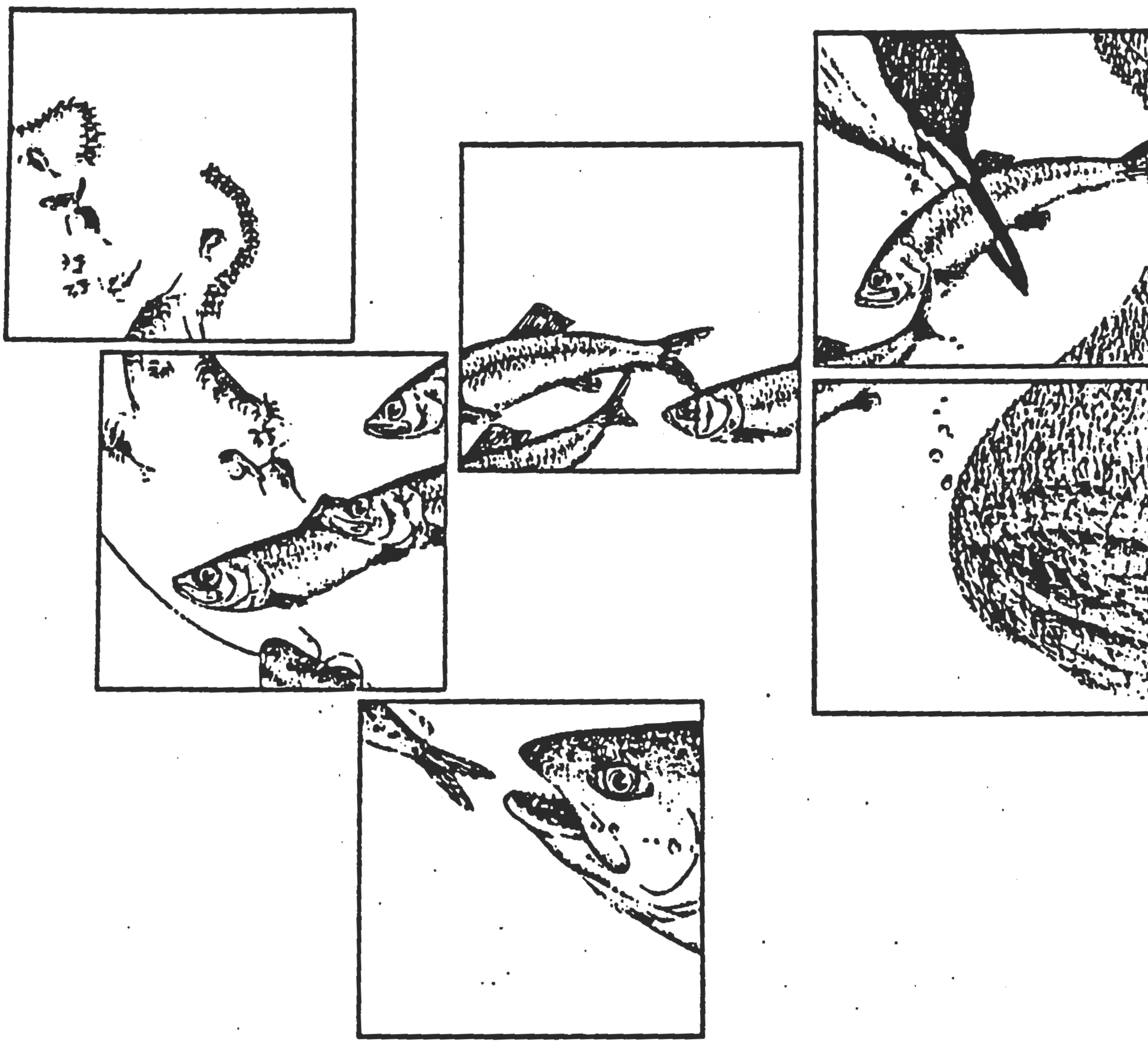
APPENDIX 3

Pacific Fishery Management Council's
Draft
Pacific Herring Fishery Management Plan

PACIFIC HERRING FISHERY MANAGEMENT PLAN



PACIFIC FISHERY MANAGEMENT COUNCIL 526 S.W. MILL ST. PORTLAND, OREGON 97201

A-4.1

SECOND DRAFT

PACIFIC HERRING PLAN

This document has been prepared for review by the Pacific Fishery Management Council on November 11-12, 1981 in Portland Oregon, and may be subject to substantial changes.

A-4.2

INTRODUCTION

This fishery management plan (FMP) has been developed by the Pacific Fishery Management Council (PFMC) to manage the Pacific herring (*Clupea harengus pallasi*) resources in the Fishery Conservation Zone (FCZ) off the coasts of California, Oregon, and Washington. There are no domestic commercial herring fisheries in the FCZ, although an experimental offshore fishery occurred off the Washington coast in 1979 and 1980. Herring are presently harvested inshore under state management.

The PFMC determined that an FMP is necessary for the following reasons:

1. There is increasing industry interest in developing offshore herring fisheries for food and bait. The 1980 experimental fishery clearly demonstrated the potential for a fishery.

2. The authority of states to manage in the FCZ is uncertain.

3. Without an FMP, vessels can circumvent state management by landing in another jurisdiction.

4. Provisions for or control over joint venture or foreign fisheries is uncertain without an FMP.

5. Herring of US and Canadian origin intermingle in the FCZ

In March 1980, the Council adopted the primary management philosophy that social conflict and disruption of existing fisheries was to be avoided. Alternate philosophies included maximizing net economic return, and maximizing physical yield.

For the purpose of this plan, three distinct management units were established based on information concerning herring aggregations in coastal waters. The northern area includes transboundary mixed stocks of British Columbia and Washington origin found along the northern Washington coast. The central area includes the range of small stocks from southern Washington to northern California. The southern area encompasses the probable range of central California herring, primarily from San Francisco Bay. Available information strongly suggests that discrete populations of herring occur in the FCZ, but the data are not detailed enough to define these populations.

Description of the Fishery and Management

Herring along the Pacific coast are primarily caught commercially, although small quantities are taken by recreational fishermen. Many commercial uses have existed in the past, but herring for sac-roe is the major use now. The most significant fishery occurs in California, where landings have increased from approximately 1,300 mt in 1973 to 6,500 mt in 1980. Yearly landings in Washington have varied from about 1,500 - 4,000 mt, but have been approximately 2,000 tons from 1976 to 1980. Less than 100 mt are harvested in Oregon.

Herring fisheries for bait and other uses are more significant in Washington than in the other states. The Washington general purpose fishery, mainly for longline and pot bait, zoo food, or reduction to oil and meal, has harvested between 100 and 1,000 mt per year; 1980 landings were 869 mt. The Washington sport bait fishery targets on juvenile herring. Harvests have averaged about 500 mt for the past five years, and the 1980 catch was 765 mt.

An experimental herring fishery occurred off the Washington coast in 1979 and 1980. Negligible amounts of herring were taken in 1979, but landings increased to 182 mt in 1980. All herring in 1980 were taken off the northern Washington coast by a factory-trawler which froze the fish onboard. The fish entered the Japanese market for food, and the Alaskan market for king crab bait.

No directed fishing for herring by foreign nations has occurred in PFMC region, although incidental trawl catches have been reported.

Historic, world wide overexploitation of herring resources points to the need for prudent management measures. In many cases, incompatible multinational management objectives allowed fishing to exceed limits recommended by fishery scientists. Declines have also occurred when single nations allowed overfishing. A common component of overfishing this species includes harvesting juveniles as well as adults.

State management of inshore fisheries has focused on harvest quotas compatible with estimated biomass. In most cases quotas are set as a proportion of the biomass. In Washington, management of the roe fishery requires allocation under guidelines of U.S. vs Washington (the Boldt decision) which affirmed treaty Indian fishing rights.

Socio Economic Considerations

A variety of active and potential markets exist for Pacific coast herring, including food, bait, and roe. Diminished herring stocks have decreased consumption from approximately 500,000 mt to 250,000 mt in Europe, and from about 80,000 mt to 50,000-60,000 mt in Japan; this may create a large potential market for Pacific coast herring. The Pacific herring is on the lower end of sizes acceptable to the European market, but generally of a size acceptable in Japan. The domestic bait market absorbs approximately 5,000 mt of herring per year. Most is used in commercial pot and line fisheries, with less than 1,000 mt used in sport fisheries.

The Japanese market for roe dominates both value and volume for Pacific herring. As a luxury item with a limited market, severe price fluctuations for roe occur with changes in supply or demand. For roe fisheries in and adjacent to PFMC waters, Canada has the largest share. Capacity exists in the USSR, mainland China, and Korea to supply the entire roe demand, although only limited exports occur at this time. Potential exists for increased roe exports from the Bering Sea. The future of California, Oregon, and Washington roe fisheries is hard to predict, as they must compete with Alaska and Asia fisheries.

An offshore fishery would directly reduce the existing inshore fisheries. Egg skeins are too immature for use as roe, so offshore herring would be used as food or bait. Offshore catches in Oregon or California would reduce the allowable roe harvest. Off Washington, however, mixed stock herring are composed of approximately 20% Washington and 80% Canadian origin spawning stocks. A Washington offshore fishery would significantly increase overall landings in the state despite some reductions in the Washington roe fishery, but at the expense of the Canadian roe fishery.

Economic tradeoffs depend on relative price of roe and food or bait. At projected prices near $1,000 per ton for roe, $500-600 for food, and $200-300 for commercial bait, maintaining the roe fisheries will yield highest benefits for Oregon and California. The net value in Washington would increase with an offshore fishery, but would result in a larger decrease in value for Canada.

Within the Pacific region, most herring stocks are considered to be in good condition. California biomass estimates have increased each year partly because of increased survey effort; the stock is characterized as excellent. Oregon stocks, though generally small, are considered stable. The Strait of Georgia Washington herring stock has declined since the fishery began, from a combination of natural fluctuations and fishing. Continued decline could result in a closure. Most Canadian stocks are at or near historical levels, although Canadian scientists indicate that there is evidence of depletion in west coast Vancouver Island stocks.

Biological and Environmental Characteristics

Herring are a component of a diverse species complex inhabiting waters from California to Washington. In northern areas, demersal and semi-demersal species dominate; pelagic species here include herring, sandlance, smelt, northern anchovy, and salmon. Pelagic species including northern anchovy and jack mackerel tend to dominate in more southern waters. An ecosystem approach to interactions between these species, though desirable, is not currently feasible. It is well known, however, that in some regions herring are major prey for many predators. The major concern that offshore herring fishing would substantially decrease food available for salmon cannot be definitively answered. Salmon form only a small part of the biomass in the ecosystem and feed on a variety of food available; thus, it appears that a small offshore fishery for herring would have a minimal impact on salmon production.

Determination of Catch Levels

Various harvest strategies and inshore-offshore fishery effects were examined using a simulation model. Although the model cannot predict the course of events in any year, it does estimate long-term consequences of different management strategies. Two strategies examined, the harvest of all fish in excess of spawning requirement, and the harvest of a constant proportion of total biomass both give similar long term average catches. The former strategy was characterized by large fluctuations in catch, including many years with no catch. The latter strategy exhibited smaller fluctuations by spreading the harvest of strong year classes over several years. An offshore fishery would require some reduction in the inshore fisheries, or a reduction in spawning escapement, or a combination of the two.

Each state will set Acceptable Biological Catch (ABC) for fishable populations. If necessary, ABC's will be pooled for management areas. In the northern management area, an estimate of ABC for Canadian spawning stocks will be incorporated into the composite ABC. Optimum yield (OY) will not exceed ABC. If the Council sets an offshore OY, the states will set an inshore OY by subtracting offshore OY from ABC.

Total Allowable Level of Foreign Fishing (TALFF) for Pacific herring is set at zero. There is currently no harvestable surplus and there will be none in the foreseeable future.

Management Issues

Six major management issues must be considered in the formulation of a management plan.

1. Herring from many spawning areas, which probably include several independent stocks, intermingle in offshore waters. The most

complicating feature of mixed stock fishing is the need to protect depleted or weak stocks, which may preclude offshore fishing of other healthy stocks.

2. Herring as forage, especially for salmon, is often viewed as the "best use" of the species; alternatively, herring could be considered as only one of many potential diet items with little direct impact on other fishery resources.

3. Diverse biological, social, and political problems exist in the management areas, including transboundary mixed stocks (northern areas), small, discrete stocks (central area), unknown offshore distribution and migration (southern area).

4. An offshore fishery in the northern area will include a high proportion of herring which spawn in Canada. Such a fishery will increase the net value to U.S. fishermen at a larger expense to Canadian fishermen. Furthermore, international management would involve agreements between the U.S. and Canadian governments.

5. Herring harvests currently orient mainly to the unstable roe market. Diversification would likely require an offshore fishery. The present value of roe herring is significantly higher than the value of herring taken offshore.

6. Herring experience wide natural fluctuations in abundance; a management plan must be able to respond rapidly to low abundance/poor recruitment problems.

Management measures recommended in the Plan involve a proportional harvest concept, with a 20% harvest rate as the basic policy; this is the current management regime of the states for inside waters. Options for an offshore fishery include status quo (no offshore fishing) or a small quota which would be subtracted from the proportionally-derived inshore quota. Size of an offshore quota would vary by management area. Objectives of the plan favor existing fisheries, and little is known of the offshore phase of herring life history. An initial offshore fishery, if authorized, should be small, but of sufficient magnitude to be economically viable. A small, fixed quota meets these criteria. Options in the plan limit legal gear in offshore waters to trawls only, or to trawls and purse seines. Options are listed in Summary Table 1.

Summary Table 1. Proposed Management Options for Herring Fishing in the Pacific Region Fishery Conservation Zone.

MANAGEMENT AREA[1/]

MANAGEMENT MEASURE	SOUTHERN (Central and Southern California)	CENTRAL (Northern California to Central Washington)	NORTHERN (Northern Washington
Quota			
Option	1) Status Quo (no fishery)	1) Status Quo (no fishery)	1) Status Quo no fishery)
	2) Fixed quota of between 1,000-4,000 mt	2) 100-500 mt quota for an experimental fishery No more than 50-250 mt can be harvested adjacent to any one state.	2) Small quota 1,000-4,000 mt
	3) Variable annual quota of between 1,000-4,000 mt.		3) Variable annual quota of betwee 1,000-4,000 mt.
			4) Large quota of 5000-20,000 mt
Season			
Option	1) Open all year	1) Open all year	1) Open all year
	2) Closed November 1 through March 30	2) Closed January 1 through April 30	2) Closed December through May 31
Fishing Gear			
Option	1) Pelagic trawls only	1) Pelagic trawls only	1) Pelagic trawls o
	2) Pelagic trawls and seine nets	2) Pelagic trawls and seine nets	2) Pelagic trawls a seine nets
Incidental Catch Allowances	Governed by other FMPs. For groundfish, propose 15 percent of the catch p trip of 3,000 lbs., whichever is greater. We propose no retention of salmon, crabs, shrimp or any other species of shellfish or finfish.		

1/ See Section 1.4 of the Pacific Herring Fishery Management Plan for a speci description of Management areas.

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1.0 INTRODUCTION

This fishery management plan (FMP) has been developed by the Pacific Fishery Management Council (PFMC) to manage the Pacific herring resources in the Fishery Conservation Zone (FCZ) off the coasts of California, Oregon, and Washington. Traditionally, there have been no domestic commercial fisheries for herring in the FCZ and, except for a small experimental fishery off the Washington coast, there are none at the present time. Herring stocks are harvested inshore after they have migrated from offshore feeding grounds in the FCZ. State agencies manage herring in State waters. This FMP discusses the harvest of herring in the FCZ by foreign nations, but such a fishery is currently prohibited by the Preliminary Management Plan for the Trawl Fisheries of Washington, Oregon, and California.

1.1 Justification for an FMP

Although there are currently no fisheries for herring in the FCZ, a FMP is necessary for the following reasons:

1. There is an increasing industry interest in development of an offshore herring fishery for food and bait. An experimental offshore herring fishery along the northern Washington coast in 1979 and 1980 clearly demonstrated the potential for such a fishery. A commercial offshore fishery would fall under Council jurisdiction.

2. The authority of states to manage resources and fisheries in the FCZ is uncertain. This applies to vessels which process at sea as well as those which deliver to shore-based processors. Also, fishing vessels transitting from Washington to Alaska can fish for herring in the Pacific Region FCZ and land in Alaska. Effective management of such a fishery is very difficult without a FMP.

3. There is a need for a comprehensive management plan for the entire Pacific Region. State management policies differ between California, Oregon, and Washington. A vessel fishing the FCZ coastal waters of one state can circumvent effective management by landing its catch in another jurisdiction.

4. Large quantities of herring reside in the FCZ for several months each year. These could be subject to foreign fisheries unless specifically prohibited by a FMP.

5. There can be no provision for or control over a joint venture operation in the FCZ without a FMP.

6. In some areas of the FCZ, stocks which spawn in U.S. and Canadian waters intermingle. Management of these transboundary stocks is an appropriate function of the Fishery Management Council process.

The PFMC thus concluded a FMP for Pacific herring is necessary and appropriate.

1.2 Objectives of the FMP

At its March 11-12, 1980, meeting in Renton, Washington, the Pacific Fishery Management Council selected a management approach from alternatives presented by the Herring Plan Development Team (refer to source document for entire list of alternatives). The Council directed the Team to prepare a draft Pacific Herring Management plan. The primary management philosophy adopted by the PFMC is to avoid social conflict and disruption of existing fisheries while achieving maximum benefit from the herring resource. Associated with this management approach are the following goals and operational objectives.

Goals

PRIORITY I

- Prevent significant reductions in the harvests of existing fisheries;

- Improve relevant noneconomic participation values, including recognition of Indian treaty rights;

- Provide adequate forage for salmon, marine mammals and other predator species;

- Improve the effectiveness and public acceptability of management, and reduce its cost;

- Provide for the optimal management of transboundary stocks.

PRIORITY II

- Increase the sum of net economic returns to all participants in the fishery (fishermen, processors, consumers, inshore and offshore);

- Encourage the use of herring for food;

- Increase the diversity of fishing opportunities available to U.S. fishermen.

Operational Objectives

- Support continuation of established fisheries;

- Insure a continuing supply of products currently being produced and marketed;

- Give priority to historical fishing rights and practices;

- Accommodate legally established Indian treaty fishery rights;

- Minimize incidental harvest of juvenile and adult salmon;

- Maintain adequate stocks of herring for forage for nonhuman resources.

1.3 Operational Definition of Terms

1) Determinants of catch levels.

   a. Maximum sustainable yield (MSY) is an average over a reasonable length of time of the largest catch which can be taken continuously from a stock. It should normally be presented with a range of

b. Acceptable biological catch (ABC) is a seasonally determined catch that may differ from MSY for biological reasons. It may be lower or higher than MSY in some years because of fluctuating recruitment. ABC may or may not be set at equilibrium yield (EY), which is the harvest that would maintain a stock at its current level, apart from the effects of environmental conditions. It may be set lower than MSY in order to rebuild depleted stocks.

c. Optimum yield (OY) may be obtained by a plus or minus deviation from ABC for purposes of promoting economic, social, or ecological objectives as established by law and public participation processes. Ecological objectives, where they primarily relate to biological purposes and factors, are included in the determination of ABC. Where objectives relate to resolving conflicts and accommodating competing uses and values, they are included as appropriate with economic and/or social objectives. OY may be set higher than ABC in order to produce higher yields from other more desirable species in a multispecies fishery. It might be set lower than ABC in order to provide larger-sized individuals or a higher average catch per unit of effort.

2) Determination of domestic annual fishing capacity and expected harvest.

a. Domestic annual fishing capacity (DAC) is the total potential physical capacity of the fleets, modified by logistic factors. The components of the concept are:

(1) An inventory of total potential physical capacity, defined in terms of appropriate vessel and gear characteristics (e.g., size, horsepower, hold capacity, gear design, etc.).

(2) Logistic factors determining total annual fishing capacity, (e.g., variations in vessel and gear performance, trip length between fishing locations and landing points, weather constraints, etc.).

b. Expected domestic annual fisheries harvest (DAH) is the domestic annual fishing capacity modified by other factors which will determine estimates of what the fleets will harvest (e.g., how fishermen will respond to price changes in the subject species and other species, etc.).

These concepts should be placed in a dynamic context of past trends and future projections. For example, physical fleet capacity should not simply be last season's inventory of vessels and hold measurements (although this is appropriate for present interim planning), but also next year's projected movement into and out of the fishery. Vessels under construction should be included and attrition should be estimated.

c. Domestic annual processing capacity (DAP) is the total potential physical capacity of the United States fish processing industry as established by the best available information. Factors used to establish domestic processing capacity include, but are not restricted to:

(1) Past performance by U.S. fish processors (i.e., actual quantities processed of the species covered by the FMP.).

(2) Geographic location of the processing facilities.

(3) The existence of contracts to purchase the species covered by the FMP from domestic fishermen.

(4) Physical and biological characteristics of the species covered by the plan (e.g., seasonal fluctuations, the migratory habits of the species, and the handling and storage characteristics of the species).

d. Joint venture processing capacity (JVP) is that amount of DAH which will not be utilized by domestic processors (JVP = DAH - DAP).

3) Total allowable level of foreign fishing (TALFF) is the foreign allowable catch which is determined by deducting expected domestic annual harvest from the optimum yield.

1.4 Description of the Management Unit

This plan applies to all marine waters north of the border between Mexico and California and south of the border between Canada and Washington (Figure 1:1). A precise delineation of the present boundaries is included as Appendix I. If boundaries are modified for any reason, this plan will apply to the boundaries acknowledged by the U.S. government.

The management region includes waters under both state and federal jurisdiction. Because herring occur in state and federal waters at different times of the year, the management regime for each must be considered jointly if they are to complement one another and be effective in achieving their objectives.

Though this FMP devotes much discussion to the management regimes and fisheries which occur in state waters, it promulgates regulations only for waters of the FCZ.

For purposes of this plan, the fisheries and the herring resources of the Washington-California region can be separated into three distinct management units. The separation is based on the best available information concerning location of herring aggregations in coastal waters. The first aggregation, composed of mixed stock herring which spawn in British Columbia and Puget Sound, Washington, can be found along the northern Washington coast and the west coast of Vancouver Island. The U.S. segment of this area is designated the Northern Management Area. The second aggregation, spawning stocks primarily from San Francisco Bay, move offshore of the central California coast, but their distribution offshore is not known. This region has been designated the Southern Management Area, with broad boundaries to encompass these fish. No large spawning stocks nor large offshore aggregations are known to exist from northern California to southern Washington, an area designated the Central Management Area. As a convenience, management unit boundaries were chosen to correspond with existing INPFC statistical areas. The areas are:

1. <u>Southern Management Area</u> - U.S./Mexico border to Cape Mendocino, California (40°30'N. latitude). Large stocks of herring from San Francisco and Tomales Bays are present in this area and are currently heavily exploited in inshore waters.

2. <u>Central Management Area</u> - Cape Mendocino, California to Cape Elizabeth, Washington (40°30'N. to 47°20'N. latitude). Small stocks are present in and adjacent to embayments along this coastal area. Fisheries are small in this area.

3. <u>Northern Washington</u> - Cape Elizabeth to U.S./Canada boundary (North of 47°20'N. latitude). Spawning stocks from British Columbia and Puget Sound form mixed stock aggregations in the U.S./Canada transboundary area but can be managed by the Council only in the U.S. portion. Stocks in U.S. and Canada are heavily exploited in inshore waters.

The herring resources and fisheries in these areas are described in Sections 3.0, 4.0 and 7.0.

2.0 DESCRIPTION OF THE FISHERY

2.1 Areas and Stocks

Pacific herring stocks extend from San Diego, California northward along the coasts of Oregon, Washington, British Columbia, and Alaska and across the Pacific rim to Asia. Vancouver Island, British Columbia, demarks the approximate southern limit of consistent high concentrations of herring in the eastern Pacific. While relatively large quantities of herring spawn along Vancouver Island and in the Canadian Strait of Georgia, lesser amounts are found in Washington State waters and in the San Francisco Bay area of California. Small quantities of spawning herring also occur within Puget Sound and in embayments along the ocean coast.

Analysis of meristic and morphometric characteristics for prespawning herring from Vancouver Island during the 1930's showed statistically significant differences between fish from various areas (Tester 1937). This analysis implied the presence of discrete populations. Subsequent tagging of Vancouver Island herring showed that straying occurred between major spawning areas but was generally limited to 20% or less (Harden Jones 1968).

More recent analyses showed that genetically discrete herring populations exist in the Pacific Ocean, at least for widely separated areas (Grant, in prep). Electrophoretic techniques identified gene frequencies for herring south of the Aleutian Islands (eastern North Pacific) as significantly different from herring north and west of the Aleutian Islands (Bering Sea and western North Pacific). Small scale differentiation occurred within the two major groupings, but was insufficient to identify components of mixed stocks.

The problem of stock identification has not been resolved, but each spawning area that supports a commercial fishery is managed as if it contained a genetically distinct stock.

In California, known spawning areas include San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, San Francisco Bay, Tomales Bay, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City Harbor.

During the summer months, herring are found in fishable concentrations in Monterey Bay. The origin of herring in Monterey Bay is unknown but is assumed to be a mixture of several spawning stocks, with Tomales Bay and San Francisco Bay the major contributors. Historically, herring spawning in Oregon has occurred entirely within coastal estuaries including Coos, Umpqua, Yaquina, Tillamook and Columbia.

Biological data collected from prespawning herring aggregations in Puget Sound, Washington suggest that genetic differences may exist (Trumble 1979). For example, statistically significant differences between the variables L and K of the von Bertalanffy growth equation were detected for three areas of Puget Sound. Herring from the three areas also demonstrated noticeably different patterns of annuli deposition on scales. Differences include consistent disparity in the reliability of scale interpretation for aging, as well as differences in growth patterns. Two of the three aggregations occur at similar times in southern Puget Sound, and the third is from northern Puget Sound and occurs several months later.

In summary, available evidence strongly suggests that discrete populations of Pacific herring occur in PFMC region waters. The data are not detailed enough to assign boundaries to spawning grounds which make up the individual populations, to determine the total number of such populations, or to estimate the amount of straying which may occur.

2.2 History of Exploitation

2.2.1 Domestic Fishery

Commercial landings dominate herring catches in the PFMC region waters. Commercial uses include sac-roe, reduction to oil and meal, bait, animal food, and human consumption. Small quantities are caught by recreational fishermen for personal use as bait or food. Recreational fishermen in some areas rely on a supply of herring for bait but depend on a commercial fishery to supply this bait. The states of California, Oregon, and Washington contain various combinations of these fisheries, but their relative importance varies by state.

2.2.1.1 Catch Trends

Annual landings have varied greatly over the years (Table 2-1). It should be recognized that the fluctuations in annual landings may well reflect market demand rather than availability of fish or stock size. The history of landings is characterized by cycles resulting from demands for herring for specific purposes.

The California herring fisheries since 1916 exhibit three major cycles (source document). Landings reached 3,600 mt in 1918 during a reduction fishery which extended from 1916 to 1919. Herring were harvested as a replacement for the declining sardine fishery from 1948 to 1953 with a peak of 4,307 mt in 1952. The current roe fishery began in 1973; landings totalled 6,447 mt in 1980, with 5,832 mt taken in San Francisco Bay.

Oregon's landings since 1928 have been principally for bait and do not show any definite trends. Annual catches were highly variable with peak landings approximately 45 mt per year.

Washington herring landings since 1935 show two main periods of catch. The first period, through 1956, was characterized by generally low landings ranging from approximately 50 mt to 500 mt. Catches were used primarily for halibut and crab bait through about 1950, with a shift toward bait for recreational use during the early 1950's. Landings jumped dramatically during the second period, regularly exceeding 2,000 mt when the general purpose fishery began in 1957. The general purpose fishery, originally for meal and oil, but more recently as bait for line and pot fisheries dominated the landings until about 1970. General purpose landings began declining after 1970, but this reduced production was compensated for by the sac-roe fishery which began in 1973.

Table 2-1. Commercial landings of Pacific herring by state,[1/] 1960-1980 (metric tons).

	STATE		
Year	California	Oregon	Washington
1960	817	4	1,861
1961	636	8	1,634
1962	592	7	2,889
1963	286	7	3,167
1964	158	15	1,674
1965	234	23	3,790
1966	110	42	2,048
1967	123	38	2,924
1968	162	17	2,924
1969	77	35	3,764
1970	143	20	2,004
1971	109	12	1,718
1972	52	12	1,566
1973	1,276	19	3,130
1974	2,382	26	5,506
1975	1,099	32	5,961
1976	2,123	35	2,683
1977	4,401*	25	3,023
1978	5,239*	63	2,933
1979	4,236*	79	3,517
1980	6,447*	64	3,228*

* - Preliminary

1/ - Data from state agencies

Current herring fisheries are predominantly roe fisheries. In California, only Tomales Bay and San Francisco Bay support major fisheries. Humboldt Bay and Crescent City Harbor stocks are relatively minor and support very limited fisheries. Relatively small sport fisheries exist in San Francisco Bay and the Noyo River.

The roe fishery began in Tomales and San Francisco Bays in 1973. For the first three seasons, the fishery was controlled by the state legislature which set very conservative catch quotas. In 1976 the Fish and Game Commission assumed control of the fishery, and expansion of the fishery began. The 1980 catch quotas totalled 6,630 mt.

Oregon presently has two herring fisheries, one in Yaquina Bay for sac-roe and one in the Umpqua estuary for bait. The total landings in 1980 were 64 mt.

Three commercial fisheries for herring presently occur in Washington: sac-roe, general purpose, and bait used by recreational fishermen. The sac-roe fishery is restricted to April and May in the Strait of Georgia and adjacent waters. This fishery exploits the largest known herring population in Washington. Yearly landings have varied from 1,500 to 4,000 mt, and have been approximately 2,000 mt since 1976. The 1980 catch totaled 1,434 mt.

The general purpose fishery occurs in specified areas of northern Puget Sound. The fishery currently operates on a limited scale, harvesting between 100-1,000 mt per year. Landings for 1980 were 844 mt. The herring fishery for sport bait is directed toward juvenile fish, in contrast to adult fish as in the other herring fisheries. The bait fishery occurs throughout Puget Sound but most catches are taken from southern Puget Sound and northern Hood Canal-Admiralty Inlet. Landings for the past five years have averaged about 700 mt, although landings are slowly increasing; the 1980 catch was 768 mt.

An offshore experimental herring fishery harvested approximately 182 mt in the FCZ off Washington in 1980.

2.2.1.1.1 Offshore Experimental Herring Fisheries

During the summer and autumn of 1979 and 1980, the Washington Department of Fisheries authorized a limited, experimental offshore herring fishery in the FCZ off the northern Washington coast. Following a recommendation by PFMC in February 1979, the WDF and NMFS implemented a research program to obtain information on the offshore phase of the herring life cycle, and information about the herring resource and the effects of offshore fishing.

Only negligible landings occurred during the 1979 experimental offshore herring fishery. Landings increased substantially in 1980 with two vessels landing about 182 mt of herring in 70 tows. While the season was open from July through December, all fishing activity occurred after late September. Few herring of suitable size were available at seasons' end. (Trumble and Reid, 1981). Two boats fished in 1980; 70 directed tows were made, and about 182 mt of herring were landed. The season extended from July through December, but all activity occurred after late September. Landings occurred in mid-October and mid-December. By late December, few herring of suitable size were available.

All landings were taken off the northern coast of Washington, mainly along the U.S.-Canada fishing boundary, by one vessel which made two successful trips. Virtually no herring were located off southern Washington during exploration by a second vessel.

Herring retained in the fishery were generally of a size suitable for a human consumption market. The Japanese market apparently will accept herring as small as 17 cm (7 inches), but prefers fish greater than 20 cm (8 inches). However, catches during the experiment had too many fish in the 17-20 cm size range to be considered prime quality. Approximately two-thirds of the herring entered the Japanese market for use as food for humans. The remainder of the catch, though of a suitable size for food, was transported directly to Alaska for use as king crab bait, because a marketing agreement could not be reached with Japanese importers.

All herring landed during the experiment were frozen on board a factory-trawler. Immediate processing provided for high quality herring, but catch rates were limited by processing capacity. Periods of several days during which herring could not be found limited the success of the factory-trawling operation; non-productive time resulted in longer trips or less than capacity loads, and reduced profitability of the experiment. Since none of the vessels engaged in the experimental fishery brought in a load of herring for shore processing, the quality or volume tradeoffs are not known.

Yellowtail rockfish made up the bulk of the incidental catch, with dogfish next in abundance. Yellowtail incidence was very high on Trip 1 for nearly a week of fishing, but dropped off after specific efforts to avoid them. Small quantities of yellowtail were caught during Trip 2. Dogfish could not be avoided during the experiment. Salmon were the only prohibited species caught. Highest catch rates of salmon occurred when herring were absent or low in abundance. (Further details are presented in Trumble and Peterson, 1980 and Trumble and Reid, 1981)

2.2.1.2 Description of User Groups

Commercial fishermen currently operate within the states' three-mile territorial waters. Herring in California, Oregon, and Washington are fully utilized. The roe fisheries which dominate landings do not currently conflict with other herring fisheries.

Recent federal court rulings such as U.S. vs. Washington (the 1974 Boldt decision), established that certain Indian tribes have treaty rights to fish herring, salmon, and steelhead and that special regulations may be required to allow the tribal members to obtain their court-ordered allocations. Washington state law prohibiting allocation between user groups originally conflicted with the federal rulings, and severe conflicts occurred between Indian and non-Indian fishermen. A 1979 ruling by the U.S. Supreme Court upheld the basic Boldt decision, and the Washington State Supreme Court subsequently ruled allowing allocation. Treaty Indian herring fishing has been mainly for sac-roe. Only limited effort by treaty fishermen has been expended on the bait herring fishery or the winter general purpose fishery.

Recreational fishermen take some herring for bait and human consumption, mainly for pickling, but also for roe in California. The magnitude of the recreational fishery is not known but is considered minor in relationship with commercial fisheries. The main use of herring by recreational fishermen is as bait obtained from the commercial bait fishery.

A component of the recreational fishing community believes that commercial herring fishing has depleted local stocks, resulting in lost forage and reduced fishing success for salmon. A major conflict between commercial and recreational users could occur if a depletion of herring actually happened.

2.2.1.3 Description of Vessels and Gear

The California herring fishery was pursued with beach seines and gillnets in Tomales and San Francisco Bays until 1952. In 1952, lampara seines were introduced in Tomales Bay and were very effective in shallow water when the lead line rested on the bottom. Lampara boats are small, between 10 and 16 meters. The smaller lampara boats load their catches onto lighters with a holding capacity of 20-30 mt of fish. The larger lampara boats have a capacity up to 60 mt.

After 1953, the lampara boats fishing in Monterey Bay supplied a limited herring market for bait and animal food. In 1973, lamparas returned to Tomales and San Francisco Bays for the sac-roe fishery. Purse seines were introduced in 1974. Drift gillnets and beach seines were used continually through the years, but gillnets did not become a major gear type until the 1975-76 season.

The fishery was dominated by round haul boats (purse seine and lampara seine) until 1977 when set gillnets were legalized. In 1978, the round haul boats were prohibited from Tomales Bay.. Gillnets currently account for over one-half the annual harvest. In 1980, the limited entry program (discussed in section 3.1.1.2) allowed 348 vessels in the fishery, of which 294 were gillnetters.

In Oregon, purse seines and lampara nets are the primary harvest gear. During the 1980 roe season in Yaquina Bay, vessels up to 20 m fished, using both purse seines and lamparas up to 270 m long.

Bait fishing in the Umpqua estuary is done entirely with small skiffs and beach seines. The boats are about 5 m long and are used to set the net and for towing the live box of fish back to the dock. The seines are usually 120-200 m long by 3 or 4 m deep. The Yaquina Bay fishery uses larger vessels to 11 m in length which employ lamparas and purse seines ranging from 90 to 200 m long.

Until the advent of the sac-roe fishery, herring fishing in Washington normally consisted of purse seiners who fished in the general purpose fishery, and lampara seine and dip net fishermen who fished for sport bait. Herring gillnetting started with the sac-roe fishery.

Limited entry in Washington (Trumble, 1977), implemented early in the roe fishery, restricted gear to 34 purse seines (3 for bait only), six gillnet, 42 lampara, 46 dip net, 10 drag seine and one brush weir. Limited entry does not apply to Indians with treaty fishing rights. In the roe fishery all eligible non-treaty gillnet (6) and purse seine (31) fishermen participate. The exact number of treaty Indian fishermen is uncertain but there are approximately 15-18 Indian purse seiners and 250 gillneters. Gillnets are limited to 228 m in length, and purse seines to 520 m (non-treaty) and 570 m (treaty Indian).

An average of four to six purse seiners--only a few of those actually eligible--normally fish for general purpose use. In the 1980-81 season approximately 15 vessels participated. Potential participation is affected by salmon fishing in the fall, and a November-December departure to California for that state's roe fishery. Twenty to thirty active fishermen participate in the bait fishery. Lamparas are limited to 60 meters, dip nets to 3 m across, and drag seines to 110 m.

2.2.2 Foreign Fishery

Foreign fishing for groundfish off the coasts of Washington, Oregon, and California began about 1962 with the appearance of Japanese and Soviet exploratory vessels. Subsequently, Poland, East Germany, West Germany, Bulgaria and the Republic of Korea entered the fishery. Since implementation of the FCMA in 1977, only the U.S.S.R. and Poland have fished off Washington-California, and only for Pacific whiting and jack mackerel.

There has never been confirmed directed foreign fishing on Pacific herring in the Washington-California region. Poland reported herring catches of 58 mt in 1973 and 1,388 mt in 1975 while engaged in the Pacific whiting fishery. Since then, foreign herring catches have been very small and are such a minor component of the total catch that there is no requirement for reporting them. U.S. observers aboard Polish and Soviet vessels during 1977-79 reported only trace amounts (.25 kg per day) of herring in whiting catches.

There was some documented targeting in Canadian waters off Vancouver Island by two East German stern trawlers during December 1975-January 1976. Each vessel was taking about 40-50 mt per day in single tows of about 45 minutes duration. Most herring were frozen whole or filleted, but some were reduced to meal. The total catch was reported to be 1,130 mt. This fishery never fully developed because in subsequent discussions with East Germany, Canada and the U.S. discouraged further efforts in this direction. In addition, the U.S. closed the area (48°30'-47°30'N latitude) just south of the U.S.-Canada boundary to foreign trawling in 1975 to protect important Pacific ocean perch grounds. This closure effectively made large offshore concentrations of herring unavailable to a foreign fishery.

2.3 History of World Herring Fisheries

Herring have a very long history of exploitation by humans. Early relatively small fisheries for food have led to large-scale harvests for food and industrial uses within this century. Very often these fisheries intensified into actual overfishing, leading to stock failures. The major world herring fisheries will be summarized separately.

Japan

A Japanese herring fishery operated in the Hokkaido-Sakhalin area as early as 1870. Landings increased from 200,000 mt in the early 1870's to the 600,000 mt level ten years later. Fishing effort then increased greatly, and had doubled by 1908. Catches fluctuated greatly but remained in the 400,000 to 850,000 mt range until the early 1930's, when stocks began to collapse due to the very intensive fishing effort. Landings then declined rapidly and by 1938 were below 100,000 mt (Murphy, 1977).

Bering Sea

A domestic commercial herring fishery for food began in the late 1800's and continued until 1946; the peak harvest was 2,277 mt (Skrade, 1980). Foreign boats began fishing on wintering stocks in 1959. By the mid 1960's both Soviet and Japanese vessels were present (Skrade, 1980). Landings peaked in 1970 at 145,547 mt and subsequently declined. The reasons for the decline are unclear. At the present time no directed fishing for herring on the high seas is permitted although small incidental allowances are granted to the foreign trawl fishery.

A small sac-roe fishery began in Norton Sound and Bristol Bay during the 1960's. This fishery greatly expanded in 1977 and has continued since; 10,000 mt were landed in 1979.

A roe-on-kelp and bait fishery also operate in the Bering Sea. In 1979, these landed 188 mt and 817 mt, respectively.

Gulf of Alaska

A large reduction fishery operated in the Gulf of Alaska from the 1920's to the mid 1960's. Landings peaked in 1937 with 114,194 mt (Reid, 1971). Subsequently, market conditions forced closure of the fishery.

Current herring fisheries in the Gulf are for roe herring, food and bait, and roe-on-kelp. In 1979 these landed 8,619 mt, 3,316 mt, and 214 mt, respectively (Blankenbeckler, 1980).

British Columbia

The principal use of British Columbia herring from the early 1900's until the late 1920's was for export to the Oriental dry salted market. Catches increased to 85,000 mt in 1928 and then decreased as the market declined (Hourston, 1980).

The development of a reduction fishery led to increased landings from 1935 to the mid 1960's when as high as 250,000 mt were landed annually. By 1966, catches declined rapidly as the fishery collapsed under heavy exploitation. The reduction fishery was closed in 1968.

Very little fishing occurred during the next few years and stocks began to increase (Hourston, 1980). A roe fishery started in 1972; the catch peaked to the 80,000 mt level in 1976-1978 and then decreased to 10,000-30,000 mt in 1980 and 1981 under a revision of management policy.

Northwest Atlantic

Atlantic herring (*Clupea harengus harengus*) have been used by man along the Atlantic coast of Canada and the U.S. for centuries.

Total landings from this area remained fairly constant at 100,000 mt to 200,000 mt per year from 1920 to 1960. The development of new fisheries during the early 1960's led to greatly increased landings that peaked in 1968 when over 940,000 mt were taken. Catches then steadily declined to less than 246,000 mt in 1979 (Anthony and Waring, 1980).

Several distinct herring fisheries occur in the Northwest Atlantic. One is in the inshore waters along the Maine coast where juvenile fish are canned as sardines. Landings since 1950 have been as high as 90,557 mt, and have averaged 41,900 mt.

There is also a fishery in the Gulf of Maine for adult herring. Catches in this fishery escalated in 1968 when 31,900 mt were taken. Catches in recent years have ranged between 15,900 and 23,600 mt (Anthony and Waring, 1980).

The multinational Georges Bank fishery began in 1961 and developed rapidly; 373,600 mt were taken in 1968. Very heavy fishing occurred and was supported principally by several strong year classes. This fishery collapsed in 1977 due to overfishing. Landings dropped from 146,096 mt in 1975 to 2,157 mt in 1977 (Anthony and Waring, 1980).

A fishery for adult herring exists off Nova Scotia. Catches were generally high; between 1966 and 1977, landings stayed above 100,000 mt.

A major fishery occurs in the Gulf of St. Lawrence-Newfoundland area where ten separate stocks exist (Moore, 1980). A strong world market for herring led to an expansion of the fishery in the late 1960's. Landings remained above 100,000 mt from 1967 to 1973. Catch quotas kept landings since the mid 1970's at the 60,000 to 70,000 level.

Atlanto-Scandian Herring

The Atlanto-Scandian group of herring includes three stocks, the major one being the Norwegian spring spawning herring (Dragesund, 1980). This stock in the past supported multinational fisheries at several points along its migration route.

Total catch of Norwegian spring spawning herring fluctuated but stayed high from 1950 to 1967; over 1 million mt were landed annually eight times during this period (Murphy, 1977). These very intensive fisheries on both juveniles and adults finally led to the collapse of the stock. The largest annual catch (1,723,000 mt) occurred in 1966; by 1970 landings had dropped to 20,000 mt.

Beginning in 1972, the fisheries were regulated by international agreement; quotas were set to reduce landings. The critical period for the resource is probably past; a slight recovery has taken place since the late 1970's (Dragesund, 1980).

North Sea

The North Sea herring fishery has a long history of multinational exploitation (Schumacher, 1980). A fairly stable catch level around 600,000 mt occurred from the 1930's until 1963. However, this catch stability was maintained by increasingly efficient fishing methods and by increases in total effort; the catch per unit of effort (CPUE) decreased during this period (Murphy, 1977).

Landings continued to increase during the early 1960's in spite of sharply declining CPUE; the CPUE during 1966 and 1967 was only one-third of the 1956-1957 value (Murphy, 1977). Catches declined steadily from 1,425,000 mt in 1965 to 170,000 mt in 1976.

International agreements resulted in the establishment of closed seasons during 1971 to 1974 and of catch quotas starting in 1974 (Dornheim, 1978). During 1977 through 1979, a total ban on directed herring fishing was instituted. As a result of these catch limits, the stock biomass has increased from a low of about 200,000 mt to 400,000 mt in 1980 (Schumacher, 1980).

Summary

A review of world herring fisheries illustrates that depletion due to fishing effort has occurred several times. The situation may be as uncomplicated as one nation simply depleting its resource through intensive fishing or as complex as a multinational effort directed toward a single stock at several points in its life history.

3.0 HISTORY OF MANAGEMENT

3.1 Domestic

3.1.1 Regulatory Measures Employed

3.1.1.1 Fishery Conservation Zone

Historically there have been no herring fisheries in the FCZ even though regulations have been minimal or nonexistant. California has traditionally required a special permit for experimental offshore fisheries, but neither California, Oregon nor Washington had regulations restricting herring fishing in the FCZ until 1978.

During the spring of 1978, following the decline of European herring stocks and exclusion of U.S. trawl fishermen from Canada, U.S. fishermen expressed considerable interest in beginning exploratory fishing for herring in the FCZ adjacent to Washington. In 1978, the Washington Department of Fisheries enacted a regulation which made it unlawful to fish for herring for commercial purposes in coastal waters adjacent to Washington state. This prohibition was designed to prevent harvest until the concept of an offshore fishery could be reviewed by the Pacific Fishery Management Council, which would be ultimately responsible should such a fishery be allowed. Acting on a request from the PFMC to allow an experimental offshore herring fishery, the Washington Department of Fisheries in 1979 modified the total ban by establishing provisions for a permit-only fishery. An experimental offshore herring fishery using midwater trawls and purse seines with a 1,350 mt quota took place in 1979 and 1980 (Trumble and Pedersen, 1980; Trumble and Reid, 1981).

3.1.1.2 State Waters

California

Prior to 1973, there were few regulations on herring fishing in California. The first three seasons of the roe fishery (1973-1975) were controlled by the state legislature. Regulations were extremely conservative. A lottery was also instituted which was the forerunner of the present California limited entry system. In 1976, the Fish and Game Commission assumed control of the fishery. The lottery was lifted in 1978, and everyone who applied was issued a permit. A total of 352 permits was issued in 1978. In 1980, guidelines for issuing 100 new gillnet permits were established effective for the 1981 season. No new roundhaul permits will be issued. Current management strategies call for a quota set at a maximum of 20% of the previous season's spawning biomass.

Oregon

For many years, the Oregon herring fishery operated in various estuaries with virtually no restrictions, taking fish with gillnets and beach seines. Gillnets were prohibited in all areas beginning in 1957. In 1975, interest was shown in developing a roe herring fishery. The Oregon Fish and Wildlife Commission effectively prevented roe fishing by closing the general commercial fishery from January 1 to April 30. The only fishery allowed during this period was for bait. This "bait only" regulation was designed to prevent a rapid expansion of the fishery during the spawning season until data on stock size could be obtained. Fishing for roe herring was authorized in Yaquina Bay in 1979 and 1980 with a 45.4 mt quota.

Washington

Prior to 1957, regulations in Washington were designed to limit the harvest of herring. In 1915 several herring spawning grounds were declared reserves and closed during the spawning season. In 1926, a "herring line" alternated the fishery each year to "inside" or "outside". In 1940, daily catch limits and in 1950 possession quotas were also used to protect reportedly depleted stocks. Gear limits were defined in 1926 for drag seine and dip bag net, in 1937 for locations of brush weirs, in 1940 for purse seines and gillnets, and in 1950 for lamparas.

The first major change in management philosophy occurred in 1957 when reduction to oil and meal was authorized with the newly established general purpose fishery. Seining was permitted over a wider area, and daily and possession limits were abolished. No further major regulatory changes occurred until 1973, the beginning of the sac-roe fishery. For the first two years of the sac-roe fishery, management was based on closed periods during the fishery to insure unmolested spawning. Since 1975, harvest has been limited by quotas set proportional to estimated abundance. The upper limit of harvest authorized is 20 percent of the total biomass if the biomass exceeds 8,163 mt (9,000 short tons). Treaty Indian participation under the Boldt decision guidelines required maintaining allocation schedules set by the court.

3.1.2 Effectiveness of Management Measures

Conservation regulations have met the objective of maintaining spawning stocks at a level high enough to prevent recruitment problems. Limited entry in California has effectively set a ceiling on the number of vessels fishing for herring. Washington's limited entry program is not entirely successful. The nontreaty fleet is considerably larger than needed for full harvest (Trumble, 1977). Limited entry does not apply to treaty Indians and numbers of treaty Indian herring fisherman have increased significantly.

3.2 Foreign

A program to manage a foreign herring fishery has never been implemented because neither the U.S. nor Canada has identified surplus stocks. While a rather large incidental catch was reported in 1975 by Poland, U.S. observers report very minor incidental catches in recent years. Herring are included within the "other fish" incidental catch limits set by the Preliminary Management Plan for the Trawl Fisheries of Washington, Oregon, and California, and herring catch records are not recorded separately.

4.0 HISTORY OF RESEARCH

Herring stocks have been investigated extensively in areas where they are commercially important (Cushing, 1975). Early research on Pacific herring occurred primarily in Southeastern Alaska and British Columbia (Reid, 1971; Taylor, 1964; Melteff and Wespestad, 1980). Much of the information on life history characteristics and population dynamics of Pacific herring originated from research in these areas.

4.1 United States Research in the Pacific Region

Research on herring stocks in the California-Washington area was sporadic and limited until about 1970 when research intensified. Investigations of herring from the early 1900's to 1970 usually coincided with developing fisheries.

4.1.1 California

Interest in Pacific herring as a commercial species in California has followed a unique cyclical pattern, characterized by short periods of intense fishing separated by long periods of little activity. This pattern has persisted at least since 1916, when the California Department of Fish and Game began tabulating annual landings.

It is not surprising that interest from the scientific community also follows a cyclical pattern characterized by periods of research associated with intense fishing. Pacific herring are currently in the midst of the third peak in interest both from the fishing industry and the scientific community. There have been many articles written since the early 1900's describing California's herring fisheries including the reduction fishery from 1916-1919 and the human consumption fishery in the early 1950's, but there has been very little research on herring in California.

Inconclusive racial studies were conducted in the 1920's. In 1955, investigations of spawning stocks were initiated in Tomales and San Francisco Bays (Miller and Schmidke, 1956).

Due to public concern, the California Department of Fish and Game initiated a study in 1970 in Tomales Bay to assess the size of the herring resource and to develop a management plan for the harvest of herring eggs on algae (Hardwick, 1973). Research has continued in Tomales and San Francisco Bays since 1973 to determine population size, age composition, growth rates, and other biological parameters which are utilized in management of the sac-roe fisheries (Spratt, in press).

4.1.2 Oregon

Oregon has a very short history of research on Pacific herring. Since 1976, age samples from the commercial and sport fisheries have been collected. Length, weight and sex data are also available from that time. In 1977, quantitative spawn surveys were begun that resulted in biomass estimates. A good knowledge of herring spawning areas exists. Twice, in 1973 and 1979, tagging experiments were conducted to determine whether herring from the Umpqua and Yaquina estuaries intermix; these experiments have not yielded conclusive data.

4.1.3 Washington

Although commercial herring fishing in Washington began in the late 1800's, little research was undertaken until the late 1930's. Early investigations included biological and racial studies and analyses of fishery statistics (Chapman et al., 1941). No further research was conducted until the mid-1950's when life history studies and spawning ground surveys were initiated to provide data for management of the Puget Sound herring fishery (Williams, 1959).

Recent herring research in Washington began in 1971 and continues today. A comprehensive research program includes hydroacoustic stock assessment surveys (Lemberg, 1978; Trumble, Thorne, and Lemberg, 1981), spawning ground surveys (Millikan and Penttila, 1972; Millikan et al., 1974; Trumble et al., 1977), and stock identification analysis (Trumble, 1979), and recruitment studies (Penttila and Stinson, in prep).

4.1.4 National Marine Fisheries Service

During August - October, 1979, the National Marine Fisheries Service, in cooperation with the Washington Department of Fisheries and Canada, conducted hydroacoustic surveys of the herring resource in the transboundary area off the northern Washington-southern Vancouver Island coast between 47°45'-40°20'N latitude. Objectives of this effort included obtaining estimates of distribution and abundance and collecting an array of basic biological data.

5.0 SOCIOECONOMIC CONSIDERATIONS

5.1 Introduction

The dominant economic characteristics of the Pacific Coast herring fishery are diversity and variability--diversity of participants and product forms, and variability from year to year in the volume and value of production.

The variety of herring fisheries that occur on the Pacific Coast from southern British Columbia to California is described in Table 5.1. The sac-roe fisheries are economically the most significant. In the sac-roe fishery, sexually mature herring are harvested during the short (2-4 week) winter spawning season. Either whole carcass or roe (about 10 percent of whole weight) are shipped to Japan. Roe is processed into kazunoko, a caviar-like specialty product which the Japanese consume primarily during their New Year holiday season. The carcasses are dried and smoked. The 1980 estimates of roe herring harvest (in metric tons round weight) are British Columbia 17,433, Washington 1,439, Oregon 45, California 6,439.

A number of other end products are produced from Pacific herring. These include bait for both sport and commercial fisheries, animal food, and very limited amounts for human consumption. There is also a very small harvest by recreational fishermen for sport bait and human consumption. By comparison with the roe fishery, the fisheries that supply these other uses are smaller but usually occur during longer periods of the year. Harvests in 1980 (in metric tons round weight) for all uses other than roe are southern British Columbia 7,875, Washington 1,816, California 36 and Oregon 34.

The harvest and processing of Pacific herring involves a substantial number of vessels, fishermen, processing plants and processing workers, as indicated in Table 5.1. For the most part, the herring fishery augments other fishing activities such as salmon fishing, rather than providing a primary source of income or employment. Fisheries that supply herring as sport bait, however, are composed of full time commercial fishermen who make this fishery their primary income.

Table 5.1 Characteristics of Pacific herring fisheries[1/]

	Washington Sac Roe	Washington Sport Bait	Washington Winter General Purpose (Bait)	Southern British Columbia Sac Roe	Southern British Columbia Food and Bait	Oregon Sac Roe	Oregon Bait	California Sac Roe	California Bait
Legal Season	April-May	All year	Sept.-Feb.	Jan.-March	Nov.-Jan.	Jan.-March	Jan.-Dec.	Dec.-March	Apr.-Sept.
Number of purse seine Vessels (Total)	46	2	10-12	249	130	1	-	27	-
Treaty Indians	15	0	2	-	-	-	-	-	-
Number gill net vessels (Total)	206-256	0	0	1302	-	-	-	294	-
Treaty Indians	200-250	0	0	-	-	-	-	-	-
Number of other vessels	0	47-50	0	-	35	4	10	27	5
Treaty Indians	0	0	0	-	-	-	-	-	-
Investment in vessels and gear ($000)	15,184	3,235-4,030	750-1,500	72,609	40,255	*	400-420	14,000-21,800	625-1,100
Participating Fishermen (Total)	542	101-110	50-60	5,500	950	15	15	820-930	30-35
Treaty Indians	375	0	10	-	-	-	-	-	-
Landings (mt)	1,582	518	148	17,433	7,875	50	34	6,439	36
Treaty Indians (mt)	808	-	-	-	-	-	-	-	-
Ex-vessel price ($/mt)	772-882	441-1,323	221-331	*	1,732	1,323	*	1,000-3,000	110-441
Ex-vessel value of catch ($000)	*	*	*	*	*	67	*	9,940	46-71
Treaty Indians ($000)	*	-	-	-	-	-	-	-	-
Wholesale Price ($/ton)	1,323	1,654	551	*	*	1,600-1,700	3,308	*	*
Wholesale value of catch ($000)	*	*	*	60,089	4,461	85	-	-	-
Number of Processors	9	27	3	55	*	-	5	15	3
Investment in processing plant and Equipment ($000)	480-540	1,400	210-225	*	*	-	*	900	1,500
Number of processing workers	*	164-191	15-20	*	*	-	*	*	141-156
Processing worker wage ($/hr)	5.00	3.60-3.75	6.00-7.00	*	*	-	4.00-4.50	6.00-7.00	5.50
Federal and state revenue ($000)	*	*	*	*	*	*	*	129	*

1. 1980 data is used wherever available, otherwise 1978 or 1979 data is used.
2. * indicates data not yet obtained, - indicates zero entry.

The variability in volume, and particularly value, of Pacific herring harvest for roe described in Table 5.2 for Washington and California, reflects the underlying bioeconomic characteristics of the roe fishery which makes up the majority of total harvest.

The roe herring fishery serves essentially one market--the Japanese kazunoko market. By contrast, other fisheries, such as salmon and groundfish, serve a variety of consumers in different regions with several end products. Price instability is an inherent characteristic of such a single purpose product demand.

Any change in kazunoko demand will result in an approximately equal change in the total demand for roe herring. There will not usually be offsetting shifts in demand among users which result in a smaller net shift in demand at the ex-vessel level. If kazunoko demand drops by 10 percent at a given price level, then so will the demand for roe herring. Demand may be maintained by a compensating change in price.

It would, however, take rather dramatic price changes to affect the consumption of a luxury product like kazunoko. Hence, since there are no other uses for roe herring, it would take substantial price changes to keep roe herring demand equal to supplies during any period in which significant changes in demand and price occur, as in 1979 (See Section 5.2.1.2).

Roe herring supply is determined by the harvest quotas which state management authorities establish. For biological reasons discussed elsewhere, these quotas very substantially from year to year. When these quota changes are made prices must also adjust to clear the market--i.e. force demand into equality with legally mandated supply. For the above reasons, the price changes required to clear the market have been, and will continue to be, quite large.

Table 5.2 Volume and Value of Pacific Coast Roe Herring Production (1973-1980).

	Washington			California		
Year	Catch (metric tons)	Ex-vessel Value (current dollars)	Price Per Ton (current dollars)	Catch (metric tons)	Ex-vessel Value (current dollars)	Price Per Ton (current dollars)
1973	1,831	366,000	200	1,279	107,680	84
1974	3,976	1,200.000	302	2,386	556,758	233
1975	3,570	811,000	227	1,104	219,720	199
1976	1,980	729,000	318	2,186	482,783	221
1977	2,089	1,040,000	498	4,444	1,333,200	300
1978	1,934	2,032,000	1,051	5,215	3,650,500	700
1979	1,737	3,489,000	2,009	4,218	5,061,600	1,200
1980	1,435	1,110,000*	774*	6,440	9,016,000	1,400

* Preliminary

An offshore herring fishery would necessarily supply demands for products other than kazunoko, as the roe of offshore herring is not fully developed. Initial indications are that herring harvested offshore would be marketed in Europe or Japan as food herring, or on the Pacific Coast as bait for the crab and other commercial pot or line fisheries. Test fisheries were conducted in 1979 and 1980 by several groundfish trawlers under Washington Department of Fisheries regulations. To date, the results of these tests are inconclusive from the standpoint of commercial profitability.

The major economic questions which must be addressed in this plan can be seen by assuming that such an offshore fishery could profitably harvest any of several optimum yields that might be established for an offshore herring fishery in the FCZ. Any optimum yield greater than zero for the purpose of establishing a U.S. offshore food and bait fishery will involve reductions in harvest by the inshore (primarily herring roe) fisheries.

The management objectives which will govern the determination of the optimum yield for an offshore fishery include both efficiency and equity considerations. Efficiency, maximizing the net economic value of herring harvests, was established as a secondary management objective. Equity considerations that were identified among the primary management objectives include maintaining the economic positions of U.S. inshore fishermen and preserving or enhancing U.S.-Canadian fisheries relations. The latter can be viewed as a desire, other things equal, to also protect the economic interests of Canadian inshore fishermen. Hence, relevant social and economic data, as displayed in the remainder of this section, are those which can be used to relate management alternatives (offshore optimum yields) to achievement of those objectives.

5.2 Markets

5.2.1 Japan

5.2.1.1 The Japanese Food Herring Market

Japan annually consumes about 60,000 mt. of dried, salted, frozen, fresh, smoked, and pickled herring for an average total raw material utilization of approximately 77,000 mt per year.

The raw material has been supplied for the most part by domestic landings and imports of roe herring caracass, and frozen whole or dressed herring. However, with the advent of extended fishery conservation zones, Japan's catch of herring has been greatly reduced. Future Japanese domestic landings have been predicted to be about 14,000 mt, or approximately 18 percent of past supply levels.

In 1977, British Columbia exported 21,000 mt of frozen whole or dressed herring to Japan. Future exports of about 10,000 mt are expected.

The U.S. has produced an average of about 3,000 mt of roe herring carcass over the past seven years; most of this production is frozen in the round for export. With the California roe herring fishery increasing to about 7,000 mt in 1980, California, Oregon and Washington could supply approximately 9,000 mt of roe herring carcass. Alaska's roe herring fishery could supply up to 30,000 mt, based on 1980 quotas. However, biomass estimates and other biological information from the 1980 fishery indicate that Alaska herring stocks may be declining.

With domestic supplies at about 14,000 mt and imports from the U.S. and Canada in the 40-60,000 mt range, Japan could still be as much as 20,000 mt short of past levels of supply unless herring are available from other countries.

Freshness and size of the herring are critical market requirements. Product should be frozen within 24 hours of harvest. To be marketed in Japan, food herring must be at least 17 cm in length (tip of snout to base of tail). Herring 20 cm and larger carry premium prices.

5.2.1.2 The Japanese Market for Herring Roe

The world market for herring roe is restricted almost exclusively to Japan. Roe is made into kazunoko, a food traditionally served during the Japanese New Year (the first three days of January). Until 1980, Japanese consumers were willing to pay high prices for this delicacy. However, with retail prices rising 300 percent from 1977 to 1979, to about $60 per pound, consumers boycotted kazunoko in 1980. This left an estimated 60 percent of 1979/1980 inventory unsold and dropped the wholesale price from about $26 per pound to about $4.

Before the era of extended jurisdiction, Japan took most of its herring from the Okhotsk and Bering Seas. As Japan lost access to those waters, imports have played an increasingly important role. Herring roe imports have ranged between 7,000 and 12,000 mt from 1974 to 1978. The reader should note that this is the actual weight of roe and not of whole herring. The roe averages about 10 percent of the body weight.

On the western side of the Pacific, the USSR, Mainland China, and North and South Korea have exported herring roe or whole herring to Japan. The USSR has a very large herring resources. Although the Soviets have a very high domestic demand, they have the capacity to supply the entire Japanese demand if they so choose. North Korea has access to considerable stocks of herring and, because of the balance of trade problems between the two countries, exports to Japan are likely to increase. South Korea and Mainland China have limited domestic supplies at this time, but do have access to herring from other areas and can be expected to continue exporting around 1,500 mt of herring roe to Japan each year.

British Columbia has been the main supplier of herring roe to Japan, with a market percentage increasing from 31 percent in 1972 to 63 percent in 1979. With the large drop in British Columbia roe herring landings since 1978 (63,400 mt in 1978, 37,500 mt in 1979, and 16,000 mt in 1980), it appears that at least in the near term, supplies from Canada will be lower than normal. The projection for herring roe exports from British Columbia to Japan is around 2,700 mt weight of herring roe for the next several years, an equivalent of approximately 27,000 mt of round herring.

California, Oregon and Washington exported an average of 7,100 mt of whole herring to Japan in 1974-78, for an equivalent of about 710 mt of roe per year. These fisheries are at near full utilization and the quantities available for export are likely to remain stable in the near future.

The future of the California, Oregon, Washington, and British Columbia sac-roe fisheries is difficult to predict. With regard to quantities demanded, these fisheries must compete with Alaskan and Asian fisheries which have the capacity to supply all of the presently unstable Japanese roe market.

With regard to potential revenues, it would be unwise to predict the success or failure of the 1980/81 sac-roe season before the 1980/81 market in Japan gets underway. The 1979/80 market was a disaster for Japanese wholesalers and the repercussions were felt by all sac-roe fishermen in the form of greatly reduced ex-vessel prices. Prices offered by Japanese buyers are not likely to reach 1978/79 levels again but, assuming a return to a stable Japanese market at past levels of consumption, ex-vessel prices will probably stabilize at between $500 and $1,000/mt.

There is good potential for increasing roe exports from Alaska due to the large herring stocks in the eastern Bering Sea. In 1979, all of Alaska supplied 1,500 mt of herring roe--in 1980, the Bering Sea quota for roe herring was 30,000 mt, an equivalent of 3,000 mt of roe.

5.2.2 Europe (Food Herring)

In the period 1971-1977, Europe produced an annual average of 443,000 mt of frozen, dried, salted, smoked, canned, and pickled herring products, requiring approximately 570,000 mt of raw material per year.

The northeast Atlantic and North Sea supplied the market until the late 1960s when, after years of overfishing, the herring biomass was reduced to near extinction. The situation remained serious throughout the 1970s and there is currently a total ban on directed fishing on two of the most important European herring stocks.

Landings from the main herring fisheries in northern Europe have declined from over 2,000,000 mt in the late 1960s to around 450,000 mt in the late 1970s. In the past, over 50 percent of the landings went for reduction but, with the reduced supply, increasing percentages of the catch are being utilized for food products, even though much of the catch does not meet previous food quality standards.

The reduced supply has driven up retail prices with the result that consumption has markedly declined. Nevertheless, domestic supplies of around 250,000 mt of food quality herring are only about half of what the market demands, creating a favorable situation for exporting nations.

Canada's east coast fishermen have stepped into this vacuum and are supplying increasing amounts of herring in various product forms. Canada exported approximately 60,000 mt of herring products to Europe in both 1977 and 1978. The New England herring fishery has also supplied about 10,000 mt per year of frozen herring to West Germany.

With supplies of herring still less than demand at present prices, there appears to be good potential for a European market for offshore herring, provided it meets the market's quality requirements.

Size is very important and price varies accordingly. There is a small and very selective market for herring that run 7-11 per kg (20-23 cm; 8-9 inches). However, the price for fish of this size is about 10 percent less than for larger herring that run 5-7 per kg (over 23 cm). The size distribution of herring in the U.S. FCZ is 17-23 cm, with a few reaching 26 cm.

Fat content is important and should be between 10-14 percent. Freshness is also a factor and the fish should be frozen or processed within 48 hours from the time of harvest.

5.2.3 United States

The main U.S. herring markets are for bait for the pot and line fisheries for crab, halibut and black cod. Herring is also used as bait in the sport and commercial troll salmon fisheries. Approximately 5,000 mt per year are used for all bait purposes--mostly supplied from southeastern Alaska.

Bait herring for commercial purposes is sold at $200-300 (ex-vessel) per ton. Onshore processing is limited to freezing the whole herring in 20-40 lb. boxes. Freshness is the main quality requirement, although size is somewhat important. Crab fishermen prefer herring at least 5 inches long and longline fishermen prefer 8-inch herring. Bait herring utilized by sport fishermen averages $600-800 per ton. Onshore processing requires keeping live herring in holding pens, sorting individuals by size, and packaging in small quantities. Recreational fishermen usually prefer 6-inch (plug size) herring.

5.3 Social and Legal Considerations

5.3.1 Nature and Extent of Indian Treaty Fishing Rights

In February, 1974, U.S. District Court Judge George Boldt ruled that treaties signed in the 1850s gave certain Indian tribes of Washington State fishing rights to salmon and steelhead. In April 1975, Judge Boldt convened a hearing on herring, especially concerning sac-roe fishing, to establish authority and responsibility of the tribes and the Washington Department of Fisheries. Judge Boldt ruled that 11 tribes had established rights to fish herring; only four of these can fish in the present Washington sac-roe fishery.

Washington State limited entry legislation does not apply to Treaty fishermen. Treaty fisherman participation in the sac-roe fishery has increased substantially as the fishery prospered. Treaty fishermen currently participate in the other Washington herring fisheries only to a limited degree. There are currently no recognized treaty rights in the herring fisheries of Oregon or California.

5.3.2 Recreational Interests in the Fishery

California's recreational herring fishery occurs during the spawning season at San Francisco Bay and the Noyo River. Catches are not available but are considered to be minor. The fishery is controlled by a 50 pound daily limit.

Herring eggs on seaweed are also taken in San Francisco Bay by recreational fishermen. This fishery is controlled by a 25 pound (including plants) wet weight daily limit. Currently, in Washington and Oregon there is a very limited harvest of herring for recreational purposes. Sport fishermen take herring with "jigs" (multiple unbaited hooks) or dip nets. Some recreationally-caught herring are pickled or smoked for human consumption. Herring are also used as bait in other recreational fisheries. The daily limit of personal-use herring in Washington is 20 pounds per person and the Oregon limit is 25 pounds per person.

5.3.3. Community Dependence on Herring Fisheries

The herring roe fishery occurs during the winter and spring and employs many otherwise idle fishermen and processors. It is a welcome economic boost to communities involved, but herring production is small relative to total fisheries harvests, even at Bellingham, Washington and San Francisco, California where a substantial share of each states harvest is landed. Small communities within these larger areas may have a high seasonal dependence on herring. This is probably true for the Lummi Indian reservation near Bellingham, and for other areas such as Turlock, California. It is unlikely that an offshore fishery would comprise more than a small fraction of the economic base of communities in which the catch is landed, or where herring fishermen reside. Hence, there is little reason to consider secondary economic or social impacts of herring management alternatives on the non-fishing residents of these communities.

5.4 Interaction Between and Among User Groups

5.4.1 Inshore Roe Fishery

The assessment of effects of offshore herring fishing on inshore herring fisheries is based on the following estimates or assumptions, supported elsewhere in this plan:

1. In the case of a single stock offshore fishery, there will be a relationship between the level of offshore catch and the reauction in inshore biomass, determined by the natural mortality experienced by the stocks on their inward migration. Best estimates of natural mortality during this phase of the herring life cycle indicate that about 20 percent of the population available to the offshore fishery is lost to natural mortality before it is available to the inshore fishery.

2. The effects on inshore fisheries of a fishery in FCZ waters off northern Washington are complicated by the fact that an offshore fishery would harvest mixed stocks which spawn in Washington and British Columbia. This difficulty can be resolved by using the experience of the Atlantic herring fisheries that has shown that mixed stock fishing removes the fish in proportion to their stock abundance. However, as the individual stocks move to their inshore spawning grounds, they must separate from each other. If this separation begins in offshore waters, then an individual spawning stock could be harvested at a greater rate than if complete mixing occurred. For example, if herring from the west coast of Vancouver Island move north from the transboundary area in late fall or early winter, herring from Washington state would be mixed only with British Columbia spawners from the east side of Vancouver Island.

   If proportional harvesting occurs for Pacific herring in offshore waters, the effects on each inshore stock will be proportional to its share of total inshore biomass. Based on spawning stock estimates from southern British Columbia and Washington, it appears that of the herring that survive the inward migration, approximately 80 percent return to Canadian waters and 20 percent to U.S. waters.

3. Only about half of the Washington herring (or 10 percent of the total) return to areas where a sac-roe fishery is permitted. The other half return to spawning grounds in areas closed to sac-roe fisheries. Nearly all of the herring returning to Canada are susceptible to inshore fishing.

A reduced herring biomass available to inshore fisheries cannot necessarily be translated directly into lost revenues.

At one extreme, reduction in biomass by an offshore fishery would completely shut down the inshore fishery in order to maintain necessary spawning escapement. At the other extreme, only a proportion (20% in Washington, Oregon and California) of the inshore reduction would be lost to inshore harvest. In this latter case, however, the remainder of the inshore reduction would be lost to spawning escapement.

The Washington fisheries can be used as an example of the effects of offshore fishing on inshore stocks. The Washington sac-roe fisheries are managed on a percentage of biomass basis. Once a minimum adult herring biomass (9,000 short tons) has been shown to be present, 20% of that biomass is available for harvest. Below 9,000 tons no fishery is allowed. Table 5.3 shows the impact per 1,000 tons of catch in the U.S.-Canada transboundary area on inshore biomass. Two hundred tons are of U.S. origin, and 800 tons of Canadian origin. At 20% natural mortality following the offshore fishery, only 800 tons would naturally be lost to the inshore fishery (160 tons would be lost to the inshore stocks of Washington, and 640 tons to the inshore stocks of British Columbia). Only 50% (80 tons) of these Washington herring would have been available for roe harvest. At a 20% harvest rate of the remaining inshore biomass, 16 tons would be lost to harvest and 64 tons would be lost to spawning escapement. If management procedure requires that the 20% harvest rate applies to a stock throughout its range, then the inshore harvest will have to be reduced further to compensate for the additional fishing mortality offshore; in this case, the full reduction of inshore biomass will be lost to inshore harvest. As offshore harvest increases, the total inshore biomass decreases toward the 9,000 ton biomass limit for sac-roe fishing. This type of management approaches a situation of harvesting all herring above a

Table 5.3 Loss of inshore herring biomass resulting from offshore harvest in the U.S.-Canada transboundary area, per 1,000 tons of catch.

Category	United States Component (20%)	Canada Component (80%)	Total
Offshore catch	200 tons	800 tons	1,000 tons
Offshore mortality	(20%)	(20%)	
Loss to inshore biomass	160 tons	640 tons	800 tons
% available to roe fishery	(50%)	(100%)	
*Biomass available to roe (harvest 20% of available biomass)	80 tons	640 tons	720 tons
Roe harvest rate	(20%)	(all above threshhold)	
Roe harvest loss	16 tons	640 tons	656 tons
Spawn escapement loss, roe areas	64 tons	0	64 tons
*Biomass available to roe (maintain constant harvest rate)	80 tons		
Roe harvest loss	80 tons		
Spawn escapement loss, roe areas	0 tons		
Biomass unavailable to roe	80 tons	0	
Spawn escapement loss, non roe areas	80 tons	0	80 tons
Total inshore harvest loss (alternate 1)	16 tons	640 tons	656 tons
Total inshore harvest loss (alternate 2)	80 tons		
Total spawn escapement loss (alternate 1)	144 tons	0	144 tons
Total spawn escapement loss (alternate 2)	80 tons		
Total inshore loss	160 tons	640 tons	800 tons

* Alternate concepts

spawning escapement threshhold. The herring management strategy model (Section 7.0; Appendix II) shows that this generates an unstable harvest and biomass situation, with years of no harvest being probable.

The remaining 80 tons of Washington herring removed by the offshore fishery would most probably be lost to spawning escapement in areas of no roe fishery, rather than to reduced harvest.

As the fishery for sport bait targets on prereproductive herring which have not yet entered offshore waters, an offshore harvest would not directly affect the abundance of bait-sized herring. However, harvesting both juvenile and adult herring from the same stock can and has led to serious stock depletion (Melteff and Wespestad, 1980). The bait fishery would be reduced if additional mortality from an offshore harvest should seriously reduce recruitment. In the absence of a clear spawner-recruit relationship, it is not possible to determine the level of adult harvest which can safely be combined with juvenile harvest. Washington Department of Fisheries regulations minimize access to adult herring in areas where juveniles are the target of a commercial fishery.

The winter general purpose fishery harvests adult herring during a period of migration when their spawning ground destination is unknown. It is not clear if these fish are a portion of single stock, a total single stock, or a mixture of several stocks. The harvest is keyed to the general abundance, but without spawning escapement goals. Declines in the biomass would tend to lower harvest. However, fluctuations in availability of herring to the general purpose fishery may depend more on vagaries of stock composition or proportion of a stock involved than on the absolute magnitude of stock(s) abundance.

In British Columbia however, the entire biomass in excess of the desired (optimum) amount of spawners is available for harvest. Thus, a reduced biomass would either come entirely out of the fishermen's share, or would close the fishery if the biomass fell below the optimum spawning escapement level.

The assumptions above provide the basis for the following determination of the economic effects of establishing alternative optimum yields for an offshore herring fishery. A 1,000 mt offshore herring fishery would reduce the Canadian and Washington inshore roe fisheries harvest by 640 and 16 mt respectively. When offshore and inshore harvests are evaluated using the best estimates of roe and offshore ex-vessel values (Table 5.4), the effects on value of catch are as follows: the 1,000 mt of offshore catch adds $475,000 to the value of U.S. herring harvest; the reduction in inshore U.S. herring harvest is evaluated at $16,000, resulting in a net gain in the value of U.S.

herring harvest of $459,000. However, if reduced Canadian inshore harvest are also included, the loss in inshore harvest value is $656,000, resulting in a net loss of $181,000 in the overall value of herring harvests. For a 5,000 mt offshore harvest the gain in U.S. harvest value is $2,295,000 and the loss overall value is $905,000. For 10,000 mt offshore harvest the gain in U.S. harvest value is $4,590,000 and the loss in overall value is $1,810,000.

Obviously the exact nature of these trade offs will depend upon the biological and economic assumptions that underly the above calculations, particularly the prices used to evaluate inshore and offshore harvests.

However, the magnitudes of economic gains and losses are significant enough to support the conclusion that, for most reasonable assumptions, the shifting of herring from inshore to offshore harvest will increase the average value of U.S. herring harvest, but will decrease the average value of the combined U.S. and Canadian harvest.

The California herring roe fishery would also be heavily impacted by an offshore food fishery in waters adjacent to the state. Monterey Bay is the only area off California where commercial quantities of herring are known to occur during the oceanic phase of their life history. Assumming an offshore mixing of stocks, a food herring fishery in Monterey Bay would probably impact both Tomales and San Francisco Bay stocks proportionally. Since the San Francisco Bay stock is much larger than the Tomales Bay stock, the economic effect of the food fishery will be illustrated as if the entire catch were from the San Francisco Bay stock.

Table 5.4 Impact of an Offshore Herring Fishery Adjacent to Northern Washington on Ex-vessel Value of Harvest.

(thousands of dollars per year)

	Offshore Harvest (metric tons)		
	1,000	5,000	10,000
Increased offshore catch value[1]	475	2,375	4,750
Reduced inshore catch value[2]			
*Washington (20% of available biomass - alternate 1)	16	80	160
*Washington (maintain constant harvest rate - alternate 2)	80	400	800
Canada	640	3,200	6,400
Net impact on ex-vessel value of herring harvest			
Total (U.S. and Canadian) - alternate 1	-181	-905	-1,810
- alternate 2	-245	-1,225	-2,450
U.S. only - alternate 1	+459	+2,295	+4,590
- alternate 2	+395	+1,975	+3,950

1 Evaluated at $475/metric ton.
2 Evaluated at $1,000/metric ton.
* Alternative concepts

The roe herring quota in San Francisco Bay established at the end of the preceeding season. Part or all of this quota could be designated for an offshore food fishery. A quota of 10,000 tons is used for illustration.

The roe fishery is a terminal fishery, taking place on the spawning grounds when annual mortality has reduced the stock to its lowest level. The fall offshore food fishery takes place when approximately 80% of the annual natural mortality has been experienced by the stock. Thus the stock offshore is 20% larger than the same stock when it arrives at the spawning grounds. It follows that a 10,000 short ton inshore roe fishery quota would be equivalent to a (80% of) 12,500 ton quota if taken offshore. At one extreme, a 12,500 short ton catch offshore would remove 10,000 short tons from the stock by the time the stock reached the spawning grounds and would eliminate the roe herring fishery.

Using 1981 values of $1,000/short ton for roe herring and $475/short ton for food herring, any amount of offshore fishing for food herring would result in a net loss in total value of the overall fishery (Table 5.5).

A 5,000 to 12,500 short ton offshore food herring fishery would result in net losses between $1,625,000 and $4,063,000 in the ex-vessel value of the fishery. Economic losses of this magnitude are counter to the goals of this plan.

Average value over time is not, however, the only relevant object of economic choice. The inshore roe harvest will always be subject to a high degree of variability in ex-vessel prices. The reasons for this variability, as discussed above, are its dependence on a single specialized luxury market in Japan. By contrast, an offshore fishery of any size would most likely supply the more diverse food and bait herring markets in Europe, Japan, and the U.S.

During the development phase of such a fishery, there would certainly be a high degree of instability until harvest and processing techniques were developed and products gained acceptance. But once these obstacles are overcome, the fishery would have access to a far broader range of destination markets and end uses than will ever be accessible to a roe fishery. Hence, if it succeeds commercially, an offshore fishery should ultimately achieve more stable prices as well.

Table 5.5 Impact of Offshore Herring Harvest Adjacent to Central California on Ex-vessel Value of the San Francisco Bay Herring Fishery[1/]

	Offshore Harvest Options				
Offshore harvest[2/]	0	1,000	5,000	10,000	12,500
Offshore price ($/ton)	475	475	475	475	476
Ex-vessel value ($000)	0	475	2,375	4,750	5,937
Roe harvest[3/]	10,000	19,200	6,000	2,000	0
Roe price ($/ton)	1,000	1,000	1,000	1,000	1,000
Ex-vessel value ($000)	10,000	9,200	6,000	2,000	0
Total value ($000)	10,000	9,675	8,375	6,750	5,937
Net loss ($000)	--	325	1,625	3,250	4,063

1/ Assume entire offshore harvest is from San Francisco Bay stocks.

2/ California establishes quotas and keeps catch records in the English system.

3/ The 1981-82 roe fishery quota in San Francisco Bay is 10,000 short tons.

It is a well known business practice to prefer stability of costs and revenues and, in some cases, to even pay something in average returns for greater stability. Individuals who purchase insurance reflect this preference, as do investors who accept lower returns on more secure investments.

Such a preference for stability can be expressed quantitatively by using a lower interest rate to discount the more stable of two alternative benefit streams. In this case, the more stable benefit stream is the value of offshore herring harvests over time. Table 5.6 reports the annual and discounted present value of one ton of herring biomass, depending on whether it is harvested offshore or allowed to migrate inshore. In each case the undiscounted stream of revenue is assumed to continue in perpetuity.

The inshore harvest value is discounted at 10 percent in all cases, resulting in a present value of U.S. and Canadian harvest equal to $6,560 per mt of herring allowed to migrate inshore. However, if taken offshore, a range of lower discount rates is applied, from 10 percent to 6.5 percent. As Table 5.6 indicates, the breakeven point is 7 percent. That is, if the increased certainty associated with supplying a more diverse market is deemed to be worth a premium equivalent to a 3 percent return investment, then a U.S. offshore fishery will improve economic efficiency, as evaluated from a standpoint that recognizes both U.S. and Canadian interests. If a lower premium is attached to this gain in stability, then an offshore fishery will detract from economic efficiency.

5.4.2 Sport Bait Fishery

The Washington herring fishery for sport bait targets on prereproductive, juvenile herring. Although some harvest of adults occurs, management practices severely limit the opportunity to catch adult herring in sport bait areas, because intensive harvests of juveniles and adults are incompatible. A several thousand ton offshore herring fishery will remove considerably more adult herring than currently taken.

A year class will virtually all pass through the sport bait fishery before being vulnerable to an offshore fishery. An offshore fishery will not directly remove herring from the age groups targeted on by the bait fishery.

Table 5.6 Impact of an Offshore Fishery on the Present Value of Herring Harvests

Ex-vessel value per ton		U.S. Only: If Taken Offshore	U.S. Only: If Allowed To Migrate Inshore	U.S. Only: Gain or Loss From Offshore Harvest	U.S. and Canadian: If Taken Offshore	U.S. and Canadian: If Allowed to Migrate Inshore	U.S. and Canadian: Gain or Loss From Offshore Harvest
Annual		475	16	459	475	656	(181)
Present value of perpetuity							
roe fishery discounted at	roe fishery discounted at						
.100	.100	4,750	160	4,590	4,750	6,560	(1,810)
.100	.095	5,000	160	4,840	5,000	6,560	(1,560)
.100	.090	5,278	160	5,118	5,278	6,560	(1,282)
.100	.085	5,588	160	5,428	5,588	6,560	(972)
.100	.080	5,938	160	5,778	5,938	6,560	(622)
.100	.075	6,333	160	6,173	6,333	6,560	(227)
.100	.070	6,786	160	6,626	6,786	6,560	226
.100	.065	7,308	160	7,148	7,308	6,560	748

However, the combined removals of adult herring will be a management concern should an offshore fishery be authorized, because increased harvest of adults would be counter to the management philosophy of the sport bait fishery.

5.4.3 User/Interest Group Perspectives on Management Goals

This section describes an empirical study conducted to elicit user/interest group perspectives on the following eight management goals considered by the Council in the development of the Pacific Herring Fishery Management Plan.

1. Increase the sum of net economic returns to all participants in the fishery (fishermen, processors, consumers; inshore and offshore).

2. Improve relevant noneconomic participation values, including the recognition of Indian treaty rights.

3. Increase the diversity of fishing opportunities available to U.S. fishermen.

4. Provide adequate forage for predator species.

5. Improve the effectiveness and public acceptability of management, and reduce its cost.

6. Prevent significant reductions in the harvests of existing fisheries.

7. Provide for the optimal management of transboundary stocks.

8. Encourage the use of herring for food.

The sample consisted of eight Pacific Council Advisory Panel (AP) members and eight additional subjects recommended by the AP. Roe fishermen were considered in one category despite the fact that they resided in different states. Similarly, a charter vessel representative was considered together with recreational fishermen.

Two general perspectives emerge from an analysis of the results: a majority perspective and a minority perspective.

Majority Perspective

Twelve of the sixteen subjects agreed that prevention of significant reductions in the harvests of existing fisheries, and provision of adequate forage for predator species were the two most important considerations in the management of the offshore herring fishery. The lack of knowledge of the effects of an offshore fishery, economic self interest, and the reliance of salmon on herring for food were the main reasons given for the importance assigned to these two management goals.

There was also a general consensus among the majority group that the goal of improving of non-economic participation values, including the recognition of Indian treaty rights, was the least important goal. The low importance given to this goal was due to this goal's lack of regard for the importance of economic benefits. Most commercial fishermen are very sensitive to management decisions that might affect their income and are therefore opposed to management goals that downplay the importance of economics in fishery management. Other reasons given for assigning low priority to this goal revolved around individual opposition to Indian treaty rights, and from a lack of understanding of the meaning of the goal.

Increasing the diversity of fishing opportunities available to U.S. fishermen and encouraging the use of herring for food were also given low priority. There was skepticism concerning the viability of the offshore fishery as well as fear that offshore fishing would lead to depletion of herring resources.

Minority Perspective

Four of the sixteen subjects shared a minority perspective favoring offshore fishery development. Encouraging the use of herring for food and increasing the diversity of fishing opportunities available to U.S. fishermen were considered highest priority. Some of the reasons for the high priority given to these goals included the importance of utilizing the herring resource for human consumption, the perception that a food market exists for the offshore herring.

Like the majority group, the minority group gave lowest priority to improving noneconomic participation values, including the recognition of Indian treaty rights. They offered similar reasons for doing so.

The minority group reacted with skepticism to the two goals which received highest ratings with the majority group, prevention of significant reductions in the harvests of existing fisheries, and provision of adequate forage for predator species. The minority group was sensitive to the fact that offshore herring populations are possibly related to the inshore herring fisheries and offshore salmon fisheries. Until the relationships are established, they felt there should be no blanket condemnation of an offshore fishery. The general attitude was that if there are unutilized resources in the offshore waters, they should be made available to offshore fishermen.

6.0 BIOLOGICAL AND ENVIRONMENTAL CHARACTERISTICS

6.1 Life History Features

6.1.1 Distribution and Migration

The Pacific herring is found along the North American coast from Baja California to Cape Bathurst in the Beaufort Sea. The Asian distribution is from the Lena River in the Arctic Ocean to Korea (Hart, 1973).

Abundance south of British Columbia is irregular and commercial quantities occur only in limited areas. In the California-Washington region, large commercial quantities of herring are found in Tomales Bay and San Francisco Bay in central California (Spratt, in prep.) and in northern Washington (Trumble, 1980). Only small separated populations have been observed in the large area from north of Tomales Bay to northern Washington.

Pacific herring aggregate in ocean feeding grounds from late spring to early autumn. They then commence an inshore migration, spawn during the winter and spring, and subsequently move offshore to feed.

6.1.2 Spawning

Pacific herring generally deposit their adhesive eggs on marine vegetation in the intertidal and shallow subtidal zones in a range of about +2m to -7m in tidal elevation. The type of vegetation or substrate used depends mainly on the spawning locality. In sheltered bays and along sandy beaches the dominant substrate is eel grass, *Zostera marina* (Taylor, 1964), along rocky shores a variety of algae.

Herring eggs incubate on the vegetation for about two weeks. Hatching time is dependent upon temperature and other factors (Outram and Humphreys, 1974; Galkina, 1971). Initial spawn density varies from an egg or two per square inch of substrate surface to upwards of 2,000 eggs per square inch in layers six to eight eggs thick. Predation by birds, fishes and other animals, thermal stress, desiccation (for spawn exposed during low tides) and wave action all cause mortality during incubation (Outram, 1958; Taylor, 1971a; Jones, 1972; Dushkina, 1973). Mortality rates during the incubation period vary from year to year in an unpredictable manner depending on weather, spawn intensity and predator population levels. Thus, there is no clear-cut relationship between the numbers of eggs deposited and the eventual number of fish hatching and surviving to adulthood (Taylor, 1963).

6.1.3 Larval Development

At hatching, herring larvae average 8mm in length. Immediately after hatching, the larvae have no swimming ability and are dispersed by tidal currents. About one week after hatching, the larvae, about 10mm in length, have absorbed their yolk sacs and have been feeding on tiny planktonic organisms. About six weeks after hatching, they are approximately 20mm in length and start developing swimming powers. At about 10-12 weeks in age, the larvae are about 30mm in length and undergo metamorphosis from the slender, nearly transparent larval form to the green/silver form recognizable as herring.

Natural mortalities of herring during the larval stages, as with the incubation period, are generally very high due to predation, competition and starvation. Cushing and Harris (1973) suggest that year class strength is determined by density dependent factors during the larval drift period.

6.1.4 Juvenile Development

Upon completion of metamorphosis, juvenile herring are free swimming and begin to form shoreline oriented schools. The schools enlarge and move out of the bays as summer progresses (Taylor, 1964).

Juvenile herring from many areas of British Columbia migrate to offshore feeding areas during the late spring-early fall period in their first year of life. In central and southern Puget Sound, most juvenile herring overwinter and migrate to offshore feeding grounds from March to July.

The distribution of juveniles in Oregon and California has not been extensively investigated but limited data suggest that their migrations follow the general pattern of the juveniles in northern areas.

Very little is known about the juvenile stage from the time they leave the inshore waters in their first summer until they are recruited to the adult population.

6.1.5 Offshore Life History

Little information is available regarding the distribution, abundance, behavior, and ecological relationships of herring once they arrive in offshore feeding areas. One of the more recent and productive studies was a cooperative trawl/hydroacoustic survey conducted by the NMFS, WDF, and Canada in the area off northern Washington - southern Vancouver Island during the late summer of 1979 (unpublished ms. Nelson & Munnalle). This study resulted in a total estimated biomass of 213,563 mt with 31,000 mt (14.6%) found on Cape Flattery Spit in U.S. waters and the remained on LaPerouse Bank (114,671 mt) and Swiftsure Bank (41,631 mt) in Canadian waters. Other Canadian studies have indicated a higher proportion of the biomass occurred in U.S. waters. No significant amount of herring were seen in other parts of the surveyed area. The ecological relationships of offshore herring are not understood, but herring, Pacific whiting, and dogfish sharks were the most abundant species taken in trawl hauls accounting for 94% of the weight of the total catch. Incidental catches of salmon occurred in 17 midwater trawl hauls aimed at herring concentrations. The highest incidence occurred on Swiftsure and La Perouse Banks in Canadian waters where 14 and 41 lbs. of salmon per metric ton (mt) of herring, respectively, were observed in catches. On Cape Flattery Spit in U.S. waters, the incidence was only 1.5 lbs. of salmon per mt of herring caught.

The biological data suggest that one-and two-year old herring do not associate with adults offshore. Two-year-olds were found in the same area as adults, but they seemed to maintain discrete schools. It appeared that new recruits begin joining adult schools at three yers of age, but even the three-year-olds may not be fully recruited until late in the year when the shoreward spawning migration occurs. Further study is needed to confirm this apparent behavior.

action all cause mortality during incubation (Outram, 1958; Taylor, 1971a; Jones, 1972; Dushkina, 1973). Mortality rates during the incubation period vary from year to year in an unpredictable manner depending on weather, spawn intensity and predator population levels. Thus, there is no clear-cut relationship between the numbers of eggs deposited and the eventual number of fish hatching and surviving to adulthood (Taylor, 1963).

6.1.3 Larval Development

At hatching, herring larvae average 8mm in length. Immediately after hatching, the larvae have no swimming ability and are dispersed by tidal currents. About one week after hatching, the larvae, about 10mm in length, have absorbed their yolk sacs and have been feeding on tiny planktonic organisms. About six weeks after hatching, they are approximately 20mm in length and start developing swimming powers. At about 10-12 weeks in age, the larvae are about 30mm in length and undergo metamorphosis from the slender, nearly transparent larval form to the green/silver form recognizable as herring.

Natural mortalities of herring during the larval stages, as with the incubation period, are generally very high due to predation, competition and starvation. Cushing and Harris (1973) suggest that year class strength is determined by density dependent factors during the larval drift period.

6.1.4 Juvenile Development

Upon completion of metamorphosis, juvenile herring are free swimming and begin to form shoreline oriented schools. The schools enlarge and move out of the bays as summer progresses (Taylor, 1964).

Juvenile herring from many areas of British Columbia migrate to offshore feeding areas during the late spring-early fall period in their first year of life. In central and southern Puget Sound, most juvenile herring overwinter and migrate to offshore feeding grounds from March to July.

The distribution of juveniles in Oregon and California has not been extensively investigated but limited data suggest that their migrations follow the general pattern of the juveniles in northern areas.

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6.1.6 Maturation and Fecundity

It appears that the onset of sexual maturity occurs earlier in the Pacific herring's southern range and progressively later proceeding northward. Stocks in California mature at 2 and 3 years of age (Spratt, in press) whereas herring in Washington and British Columbia mature between ages 3 and 4 (Trumble, 1980; Outram and Humphreys, 1974). Bering Sea herring spawn for the first time at ages 2-6 but the majority do not spawn until ages 3 to 5 (Barton, 1978).

Paulson and Smith (1977) reported an apparent decrease in fecundity at a specific length with increasing lattitude which is offset by a larger mean length at age for reproductively active females.

Average fecundity is about 20,000 eggs per female. Fecundity by age for selected populations is presented in Table 6.1. Eggs per female from most areas range from slightly under 10,000 for age 2 herring to over 40,000 for age 7 herring (Rabin and Barnhart, 1977; Katz, 1948; Nagasaki, 1958).

6.1.7 Age and Growth

Pacific herring have been found to attain an age of 15 years (Barton, 1978) but they generally occur in fisheries of the California-Washington region from ages 2-6 (Spratt, 1976; Day, 1980). Examples of age compositions of populations from selected areas are presented in Figure 6.1. Conclusions drawn from age composition data from any one year should be made with caution since many variables (recruitment, fishing mortality, natural mortality, anomalies in availability, fishing gear and methods, etc.) may cause significant year-to-year shifts in age composition within the overall age structure of the population.

Figure 6.2 shows a generalized growth curve for Pacific herring. At the end of the first year of life, herring reach 9-10cm in length. By age 3-4 (first spawning), their average length is about 16-18cm. Growth slows markedly after age 4 in most stocks, the average length at age 8 being about 22cm.

Table 6.1. Fecundity versus age for Pacific Herring of various regions. Modified from Paulson and Smith, 1977.

	Humboldt Bay[a/] California		Puget Sound[b/] Washington		Southern[c/] British Columbia		Northern[c/] British Columbia		Prince William Sound Alaska	
Age	Fecundity	Sample Size	Fecundity	Sample Size	Fecundity	Sample Size	Fecundity	Sample Size	Fecundity	Sample Size
I			8,808	11	10,244	4				
II	12,874	11	15,815	17	14570	48	14,298	10	13,992	4
III	24,545	5	16,842	8	18,811	65	20,416	153	17,965	21
IV	28,637	5	26,414	2	22,404	29	24,695	45	22,528	26
V	36,286	3	38,376	1	25,695	7	31,098	19	23,391	98
VI	45,373	3	35,279	2	27,072	1	41,052	4	24,347	7
VII	42,101	3	39,914	1	26,287	1	34,639	1		
Mean Length of Spawning Females	161mm		169mm		195mm		197mm		212mm	

a/ Rabin and Barnhart (1977)
b/ Katz (1948)
c/ Nagasaki (1958)

oc

Growth rates may consistantly vary between populations, even within small geographic areas. Von Bertalanffy growth parameters for several Pacific and Atlantic herring stocks are shown in Table 6.2.

6.1.8 Food and Feeding

Herring larvae start feeding on small planktonic organisms. During the postlarval stage, they consume a wide variety of organisms, among the most important are copepods, mollusc larvae and pelagic eggs. The predominant food of adult herring appear to be macrozooplankton, primarily copepods and euphausiids.

Herring search out and choose their prey rather than filtering the water indiscriminately. They are opportunistic feeders and will take what food becomes available. Larval herring, at the earliest stages, are size selective in seeking prey but become more opportunistic as their ability to capture a wide range of prey species increases. Their intensity of feeding varies with area and time of year. Mature herring feed most intensively in the spring after spawning and during the summer; they feed lightly in fall and winter.

6.1.9 Natural Mortality

Mortality is highly variable during embryonic development. Taylor (1964) found that egg mortality in British Columbia ranged from 55-99% and averaged 70-80%. Recent studies in British Columbia, however, have concluded that mortality during the eggs life averages less than 20 percent (Haegele, et al, 1981). In the Strait of Georgia, Washington, egg mortality ranges from 90 to 99 percent (Palsson, pers. comm.). Major causes of mortality are wave action, exposure to air (desiccation and freezing) and bird predation.

Juvenile mortality is likely more similar to adult mortality in magnitude and degree of variation than to larval mortality. In years of high egg and larval survival, juvenile mortality could be very high from intraspecific competition for food and from increased predation.

Table 6.2 Von Bertalanffy growth parameters for selected stocks of Pacific and Atlantic herring.

	L∞ (mm)	K	Reference
Pacific			
San Francisco Bay, CA	208	.59	Spratt, Pers. comm
Tomales Bay, CA	224	.47	Spratt, pers. comm
Case Inlet, WA	197	.59	Trumble, 1979
Carr Inlet, WA	230	.48	Trumble, 1979
Strait of Georgia, WA	263	.36	Trumble, 1979
Bristol Bay, AK	299	.18	Warner, 1976
Eastern Bering Sea, AK	314	.35	Bering/Chukchi Sea Herring Plan
Atlantic[1,2]			
Western Gulf of Maine	346	.40	
Georges Bank	333	.51	

1/ From "Environmental Impact Statement/Fishery Management Plan for the Atlantic Herring Fishery of the Northwest Atlantic". Prepared by the New England Fishery Management Council.

2/ 1968-1971 year classes.

Herring are preyed upon in their juvenile stages of their life cycle by invertebrates, and at other stages by fishes, birds, and mammals. Most herring predators have an opportunistic, nonselective diet and feed on the most conveniently available prey species of the proper size. The importance of herring as a food item in an area varies in different months and years (Macy et al., 1978).

Natural mortality rates of 0.20 to 0.85 were estimated for herring stocks in southeastern Alaska and British Columbia (Skud 1963; Tester, 1955). The rates in British Columbia were found to decrease from south to north and the rate for a given age in southeastern Alaska was lower than in British Columbia. The instantaneous natural mortality of eastern Bering Sea stocks was estimated to be 0.47 (North Pacific Fishery Management Council, 1979). Total mortality (Z) estimates of Straight of Georgia roe herring, using regression techniques, have been calculated to range from 0.45 to 0.57 (Trumble, pers. comm.). Assuming an average annual exploitation rate of 20% (F = 0.22), preliminary estimates of instantaneous natural mortality would be approximately 0.23-0.35. Other stocks in Puget Sound, currently unexploited as adults, have total mortality (Z = M) calculated as 0.5 (Trumble, pers. comm.).

6.2 Stock Units

6.2.1 Biological Determination of Stock Units

Intensive spawning ground surveys have documented the existence of large spawning stocks of herring in San Francisco and Tomales Bays in California and in the Strait of Georgia in Washington. Minor spawning stocks have also been identified in many bays and estuaries along the coasts of northern California, Oregon, southern Washington, and in Puget Sound, Washington. Spawning stocks also exist along the east and west coasts of Vancouver Island close to the U.S.-Canada border.

It is likely that stocks intermingle extensively on the summer offshore feeding grounds and thus are not amenable to single stock management in the

FCZ. Accordingly, three management units have been established which best delineate stock groupings for effective management:

1. Southern Management Area - U.S./Mexico border to Cape Mendocino, California (40°30'N. latitude). Large stocks of herring from San Francisco and Tomales Bays are present in this area which are currently heavily exploited in inshore waters.

2. Central Management Area - Cape Mendocino, California to Cape Elizabeth, Washington (40°30'N. to 47°20'N. latitude). Small stocks are present in and adjacent to embayments in this coastal area. Fisheries are small in this area.

3. Northern Washington - Cape Elizabeth to U.S./Canada boundary (North of 47°20'N. latitude). Spawning stocks from British Columbia and Puget Sound form mixed stock aggregations in the U.S./Canada transboundary area but can be managed by the Council only in the U.S. portion. Stocks in U.S. and Canada are heavily exploited in inshore waters.

6.2.2 Condition of the stocks

The current status of herring stocks can be described from trends in abundance estimates made through direct observations (spawning escapement, catch, hydroacoustic) and from changes of age composition through a series of years (cohort analysis).

Four major geographic areas contribute to herring aggregations in the FCZ. Two of these are Canadian areas (western Vancouver Island and eastern Vancouver Island). Canadian spawning escapement estimates suggest that the herring stocks in these areas are stable. In U.S. waters, stocks in one area (Northern Puget Sound--Strait of Georgia) have shown a declining trend, while in the other (San Francisco Bay) they have been increasing.

Only in Canada are data available to estimate abundance trends for more than eight years. Canadian scientists estimate that present abundance corresponds closely to the peak abundance estimated for the reduction fishery of southern

Vancouver Island during the early 1960's. The western Vancouver Island stock has been estimated at about 108,000 tons and the eastern Vancouver Island stock at about 159,000 tons (W. E. Johnson, pers. comm.). About 2/3 of these two stocks are considered to intermingle with U.S. stocks. During the late 1960's, the Vancouver Island stocks declined to low levels due to overfishing during a period of poor recruitment. Following a four-year ban on reduction fishing from 1968 through 1971, these stocks made a full recovery. The level of decline was apparently not large enough to seriously affect recruitment. Canada reinstituted intense fishing in 1972 with the beginning of the sac-roe fishery. Stocks from the east coast of Vancouver Island which contribute to the offshore herring population in the FCZ are currently healthy and capable of sustaining fisheries in Canada's inshore waters. Stocks on the west coast of Vancouver Island have recently shown indications of depletion and it is becoming increasingly difficult to sustain a roe herring harvest (Humphreys, personal comm).

The Strait of Georgia (northern Puget Sound) herring population which supports the Washington State sac-roe fishery has shown a decline since surveys began in 1973. The estimated population of 14,500 tons in 1973 and 14,000 tons in 1974 dropped to approximately 9,000 tons in 1979 and 1980. Age composition data show apparently strong recruitment prior to and at the beginning of the fishery. The 1969 and 1968 year classes dominated the fishery as four and five year olds beginning in 1973. This period was followed by several years with poor to moderate recruitment. Since 1974, the 1975 year class has shown strength, recruiting into the fishery as 3 year olds in 1978 and the 1978 year class recruiting as 2 year olds in 1980.

Population estimates of Pacific herring stocks in California indicate a 1980 spawning population in excess of 54,000 mt, a catch of 6,000 mt, and a total of 60,000 mt. The San Francisco and Tomales Bay spawning escapements are estimated to be at least 47,000 mt and 5,400 mt respectively; other spawning areas support relatively minor stocks. Catch quotas have been increased gradually since 1976 and currently total about 12% of the resource available. The age structure of the catch has fluctuated from year to year but no year class failures have occurred and older age classes are still represented in the fishery. Harvesting at current levels is conservative and stocks appear in excellent condition.

6.3 Ecological Relationships

6.3.1 Environmental Characteristics

The waters off California, Oregon, and Washington are relatively cool and sub-arctic in origin (Favorite, Dodimead & Nasu, 1976). Major current systems are the Sub-Arctic Current and the California Current. The Sub-Arctic Current System is a massive easterly-flowing body, roughly between latitudes 40 and 50 degrees north. As it approaches the North American continent, it branches northward, joining the Alaska Current, and southward where it becomes the southeastward-flowing California Current. The California Undercurrent flows northerly, relatively near shore and joins the northerly component of the Sub-Arctic Current. Upwelling and coastal eddies occur seasonally. The water is characterized by high nutrient and oxygen levels. Mean ocean surface salinity is moderate, ranging from less than 32^o/oo in the north to 33^o/oo in the south. The coastline is relatively even with few major projecting capes or indentations. The continental shelf is relatively narrow but with frequent submerged gullies (Favorite, Dodimead, & Nasu 1976; Trumble, MS).

6.3.2 Biological Characteristics

The eastern North Pacific coastal region is relatively rich in nutrients, accompanied by high productivity of phytoplankton and zooplankton which support substantial populations of higher animals - fish, birds, mammals. Production tends to be richer near shore where upwelling, eddy effects and coastal runoff are strongest. Demersal and semi-demersal species dominate off Washington, Oregon and northern California, whereas pelagic species tend to dominate off southern California. Pelagic species off Washington and Oregon include sandlance, herring, smelt, northern anchovy and salmon. In addition, albacore, saury, Pacific whiting, jack mackerel, and pomfret migrate into northern waters in summer. Off California the dominant pelagic species are northern anchovy and jack mackerel. The abundance of these two species has a complex relationship with Pacific sardine and Pacific mackerel which is poorly understood.

Seals, sea lions, porpoises, and whales are common throughout the region. Substantial numbers of northern fur seals migrate seasonally northward and southward through the region (Fiscus, 1980). Many species of marine birds feed seasonally or year-round in the region and are important consumers of pelagic fish and invertebrates. Dungeness crab are very abundant north of California and their larval and juvenile forms constitute an important part of the food web for both fish and birds.

6.3.3 Ecosystem Characteristics

An ecosystems approach to fisheries management is desirable, particularly where a fishery for a given species has a substantial effect on other desirable species. Such interaction between species undoubtedly occurs in the ecosystems comprising "herring waters" off Washington, Oregon, and California. Involved are complex space-time variable processes, including: environmental phenomena, primary biological productivity, biomass levels, reproduction and growth of the major elements of the food web, interactions of predator-prey relationships, natural and fishing mortality, and vertical and horizontal migrations. Data are not presently available for a sophisticated ecosystems approach to management in the waters of concern.

6.3.4 Feeding Conditions

Herring in offshore waters feed opportunistically on a wide variety of zooplankton and nekton, including crustaceans, molluscs, cephalopods, larval fish and pelagic ova (Wailes, 1936). Food items vary according to size of herring, location, depth and seasonal and annual abundance of major prey species. There is no evidence in the literature that availability of food is a limiting factor in adult herring growth or survival. Periodic reductions in feeding may occur during winter or during spawning activity such as are common to other fish. Murphy (1977), in referring to pelagic clupeoids in general, concluded that "...in post-recruits there is little or no observable response to growth rate or fatness over wide ranges of stock size, again indicating that they are not directly food limited." This conclusion is consistent with the hypothesis of Cushing and Harris (1973) that year class strength for fish is determined during larval drift or early juvenile stages. Mathisen et al. (1979) also presented data which support the concept that food is not limiting to adult fish.

There are suggestions that offshore waters might support substantially larger populations of herring than at present. Results from a dynamic salmon ecosystem model indicate that the "apparent carrying capacity" of the North Pacific in respect to salmon can easily sustain a substantially higher standing stock of adult salmon than at present (provided that salmon are very competitive for food and predation on salmon is not a limiting factor) (Favorite and Laevastu, 1979). Since, at times, herring and salmon feed on many of the same food items (Fresh and Cardwell, 1979), the conclusions of Favorite and Laevastu might be expanded to include pelagic herring as well. However, the fact that the "apparent carrying capacity" has not been reached may suggest that adult salmon or herring abundance is dicated by mortality in the early life history or competition for critical food items at another life stage.

6.3.5 Competitors and Predators

Within the total food web, herring occur as intermediate predators on, and competitors for, smaller prey species, and herring themselves are prey for larger fish, birds and mammals. The general features of the food web in marine waters off Washington, Oregon and California have been discussed by Laevastu and Favorite (1977). This work is at an early stage, and biomass estimates and consumption rates are very approximate. An important conclusion is that most species feed upon a variety of food items so that a substantial change in abundance of a single item will not necessarily have a severe impact on the total food supply. Copepods comprised 71 percent of the diet of herring-like fishes used in this study. It is not known whether this high average copepod consumption is due to preference or relative abundance. It is also unknown whether a shortage of copepods in a given area or season could affect growth, or whether compensatory mechanisms might come into play such as vertical or horizontal migration to richer feeding areas, or more competitive feeding activity for other prey items.

6.3.5.1 Herring-Salmon Interactions

The matter of specific predation on herring by salmon will be dealt with separately because of the long-standing question as to whether herring fisheries either inshore or offshore have adverse impact on salmon growth or survival.

Pritchard and Tester (1944) examined stomachs of chinook and coho salmon off Barkley Sound and off North Vancouver Island in 1939, 1940 and 1941 for the specific purpose of resolving the "supposed conflict between herring and salmon fisheries". Their study was in response to "fears expressed as early as 1938, that herring seining would result in elimination of the salmon through reduction of the food supply." A summary of the range of identifiable stomach contents for the two species for all years and for both areas follows:

Food Item	Stomach contents (% by weight)	
	Coho	Chinook
Herring	13-34%	33-46%
Pilchard	1-5%	9-21%
Sandlance	13-41%	25-41%
Other Fish	1-35%	4-7%
Invertebrates	4-30%	2-6%

Although herring formed a substantial portion of the diet in the combined samples, species composition and dominance varied greatly between monthly periods and between sampling areas. For example, euphausiid formed 30-40% of the diet, sandlance 60-70%, and crab larvae 50-60% in some monthly sample groups.

The range of fish species eaten by salmon included herring, pilchard, sandlance, anchovy, capelin, Pacific whiting, rockfish, sablefish, saury and lanternfish. After analyzing salmon stomach samples, Pritchard and Tester concluded that "we cannot assess the effect of herring supply on salmon troll fishing without knowledge of fluctuations in numbers of salmon and factors affecting availability." They further concluded that the availability of food may cause: (1) concentrations of salmon for the benefit of fishermen, (2) salmon that are full and difficult to take on troll gear.

A direct and seemingly simple method for determining whether herring affect survival of salmon would be to compare the abundance trends of salmon and of herring over a long series of years. However, in view of the limitations in our knowledge of the behavior, distribution, and migration of both salmon and herring, it would be virtually impossible to select appropriate areas, time periods, or stocks for making a meaningful comparison. The assumptions and the conclusions would be subject to serious questions whether the data indicated a relationship or not. A host of other factors, both known and unknown, could be responsible for any apparent positive or negative correlation in abundance. This would be particularly true in comparing the abundance of herring versus salmon in the oceanic environment where stocks from many origins are mixed and free to migrate rapidly and extensively.

Canadian scientists recently conducted a preliminary study on salmon/herring dependency in Georgia Strait for the period 1960-1970 (Healey, 1976). The abstract of Healey's report summarizes his findings as follows:

> "This manuscript considers the importance of herring and the exploitation of herring to the populations of Pacific salmon in Georgia Strait. No relationship was found between the abundance of each species of salmon and the abundance of herring in Georgia Strait between 1960 and 1970, a time when major fluctuations in herring abundance occurred. Available data on food habits indicates that chinook and coho eat mainly fish while the other species eat mainly invertebrates. Herring is only one of several important forage species for chinook and coho. The herring taken by chinook and coho are generally in age-class 1+ to 3+, with few older herring being taken. Estimates of the herring requirements of all species

of salmon in Georgia Strait ranged around 12,000 tons compared with an estimated herring population of 290,000 tons. Commercial harvesting of adult-sized herring, therefore, is unlikely to influence the growth or survival of Pacific salmon in Georgia Strait."

A significant statement by Healey (1976, Page 2) with respect to the validity of his findings follows:

"Although I felt it was important to rule out any obvious direct relationship between the abundance of herring and salmon, I did not expect to find any. Failure to find a correlation over such a short time period could as easily be due to shortcomings in the information as to the real lack of relationship. Any concerted attempt to discover a relationship, whether direct or indirect, will require considerable investment of time and resources. The estimates to follow, of the food requirements of salmon, will serve to put the problem into perspective so that its relevance can be assessed against other needs."

Clearly, the problem is complex and will require a substantial effort to test for the existence or non-existence of a relationship, and is beyond the scope of this management plan. It can be said, however, that in the light of our present knowledge of the life histories of both herring and salmon, it would be highly speculative to postulate that the abundance of herring determines the survival of salmon, but herring abundance may, at times and places affect growth or even migration and distribution of salmon in some limited degree.

The work of Laevastu and Favorite (1977) makes it possible to carry the salmon/herring question one step further. For instance in Table 6.3, salmon abundance in the Washington-Oregon area is estimated at 90,000 mt and as consuming 38,000 mt, whereas their food items, particularly the "sardine" category which includes herring, is estimated at 639,000 mt and with a consumption rate of 1,165,000 mt. Biomass and consumption estimates for zooplankton are not given in Table 6.3 but would be even greater than for any of the fish species.

As shown in Table 6.4, euphausiids comprise 132,000 mt of food for the baleen whale alone, and 2,000 mt for marine birds off Washington and Oregon. Thus, salmon, as a relatively small part of the biomass of the ecosystem, have available to them massive quantities of a variety of food items. Their impact on herring and similar fishes is very small. In this perspective, a small fishery for herring off the northern Washington coast would have only a minor impact on herring considering the total biomass and removals by other ecological groups. The impact on food supply for salmon would also be minimal.

Table 6.3. "Minimum sustainable" biomass and annual consumption of selected fish types off Washington, Oregon & Central and Northern California seaward to 200 mile limit.

Fish Types	Estimates in 10^3 mt			
	Wash/Or.		Cent. & N. Calif.	
	Biomass	Consump.	Biomass	Consump.
Squid	279	455	670	1,077
"Sardine", anchovy, smelt, herring, sandlance [1/]	639	1,165	1,505	2,701
Saury, mackerel, lanternfish, pomfret	363	575	877	1,379
Salmon, tuna, bonito	90	38	233	100
Hake, cod, sablefish	387	313	862	697
Rockfish	199	159	363	322
Flatfish	123	92	204	179

1/ Mainly herring & sandlance in Washington/Oregon

Source: Laevastu & Favorite, (1977)

Table 6.4. Estimated consumption by mammals & birds of major ecological groups of food types off Washington, Oregon and Central and Northern California seaward to 200 mile limit. Source: Laevastu & Favorite (1977a).

	Consumption in 10^3 metric tons/year by									
	Baleen Whales		Toothed Whales 2/		Pinnipeds 3/		Marine Birds		TOTAL	
Food Types	Wa/Or	Ca.	Wa/Or	Ca.	Wa/Or	Ca.	Wa/Or	Ca.	Wa/Or	Ca.
Euphausiids	132	526					2.0	1.9	134	528
Copepods	26	105							26	105
Squid	17	68	90	256	13	18	1.1	1.0	121	343
"Sardines" 1/	13	53	90	256	6	8	4.0	3.8	113	321
Saury			63	179					63	179
Other Pelagic			90	256	7	14			97	270
Salmon/Tuna			27	76	2	5			29	81
Roundfish			90	256	82	138	0.6	0.5	173	395
Rockfish					26	44	0.6	0.5	27	45
Flatfish							0.6	0.5	1	1
Benthos							0.6	0.5	1	1
"Others"					5	9	1.1	1.0	6	10
TOTALS	188	752	450	1,279	141	236	10.6	9.7	791	2,279

1/ "Sardines" include herring, sandlance, smelt, anchovy.

2/ Including porpoises & dolphins.

3/ Fur seals & sea lions.

7.0 DETERMINATION OF CATCH LEVELS

7.1 Harvest Strategies

A mathematical model constructed to examine harvest strategies for herring is presented in Appendix II. The model requires information on biological characteristics (growth, mortality, recruitment) and approximate starting biomass of stocks to be considered. For a set of biological parameters, one may compare biomass, harvest levels, and population stability over a long time period for a series of management strategies. Although the model cannot be used to accurately predict the course of events in a given year, it does give an estimate of the long-term consequences of different harvest management strategies.

Several results emerged which are applicable to herring fisheries independently of biomass. Harvesting at a proper constant percentage of the estimated total biomass gives the least fluctuation of biomass and harvest. Constant harvest rates may be high enough to drive the population to depletion, but can be guarded against by setting a minimum population size as a reserve, below which no harvest may occur. This strategy will protect the resource against inadvertent overharvest, but is subject to fluctuating harvest and biomass including several years without harvests. The "surplus stock" strategy which authorizes harvest of all herring in excess of a desired spawning escapement will also maintain a long-term production from the population; however, this strategy is characterized by extreme fluctuations in biomass and harvest. Harvests extend from extremely high to many zero harvests. These strategies are currently used by existing roe herring fisheries in Canada ("surplus stock") and the U.S. ("proportional harvest").

The model predicts that long term average yields in the U.S.-Canada transboundary area could be between 40,000 and 60,000 mt, depending on the management strategies chosen. The predicted range is from 0 to 200,000 mt per year. This quantity may be taken inshore, offshore, or in both areas, and will be shared by the U.S. and Canada. At the present time all fisheries occur inshore and 80 to 90 percent of the fish are harvested in Canada.

Addition of an offshore fishery will add mortality. However, total loss to the inshore population will be less than the amount harvested, because some of the fish would have died even if an offshore harvest hadn't occurred. In the case of an offshore fishery, there will be a relationship between the level of offshore catch and the reduction in inshore biomass, determined by the natural mortality experienced by the stocks on their inward migration. Some of the fish caught by an offshore fishery would die anyway before being able to spawn, even in the absence of an offshore fishery. The longer the time period between the offshore fishery and time of spawning, the more loss will occur due to natural mortality. The herring harvest strategy model (Appendix II) calculates that from the time period of an offshore fishery (July, August, September) to spawning in March, approximately 20% of the herring biomass is lost to natural mortality. Therefore, 20% of the fish caught by an offshore fishery would have died, and 80% of the catch would be lost to the spawning population. An offshore fishery later in the season would experience a lower loss to natural mortality, so more of the offshore catch would be lost to inshore biomass.

The amount of reduction to the inshore fishery depends on the management procedure used to compensate for the offshore harvest. If inshore quotas are based on a constant proportion (i.e., 20%) of observed biomass, then the lost harvest will be 20% of biomass reduction. If management calls for a constant fishing mortality or harvest of all fish above a spawning escapement goal, then the entire inshore biomass reduction is lost to the inshore fishery. Reductions to an inshore fishery will be less than the amount harvested offshore. A U.S. offshore fishery along the northern Washington coast will cause more reduction of inshore Canadian harvest than of inshore U.S. harvest, and would increase the total U.S. catch. A U.S. offshore fishery along central California will cause direct loss to the Californian inshore fisheries.

The United States will have no direct input to management strategy of Canadian inshore fisheries. The biomass of herring will depend to a large degree on the spawning escapement established for Canada. The Canadians harvest all herring in excess of a spawning reserve; this management practice causes the most variable catches and biomass. Therefore, any harvest from management strategy for the U.S. portion of the transboundary area which is tied to biomass will likewise undergo the same large excursions.

7.2 Maximum Sustainable Yield (MSY)

Maximum sustainable yield (MSY) is an average over a reasonable length of time of the largest catch which can be taken continuously from a stock. It should normally be presented with a range of values around its point estimate. Where sufficient scientific data as to the biological characteristics of the stock do not exist or the period of exploitation or investigation has not been long enough for adequate understanding of stock dynamics, the MSY will be estimated from the best information available. These estimates of MSY are based on current fishery practices. Changes in mesh size and/or the season/area distributions of fishing effort would change estimates of MSY for most species.

Although the model can predict a MSY produced by the selected management regime, it is useful only as an indicator of what may be expected, on the average, over many years. MSY has no usefulness in setting ABC or establishing annual management programs. It must be indelibly scored on the mind of all involved in herring management that MSY is simply a predicted long-term average and has no more short-term value than the fact that a stream averages 12 inches in depth to a man in that stream up to his neck in the water.

There is also no single value of equilibrium yield at which population will remain approximately constant. Of far more use to managers and planners is a knowledge of the range of harvest values that may be expected, and the effects that various harvest strategies may have on such fluctuations. Herring is a species which undergoes large variations in annual recruitment, and there are normally only three or four year classes which contribute significantly to the biomass. Two or three successive years of poor recruitment or of strong recruitment will cause wide swings in total abundance.

7.3 Acceptable Biological Catch (ABC)

Acceptable biological catch (ABC) is a seasonally determined catch that may differ from MSY for biological reasons. It may be lower or higher than MSY in some years, because of fluctuating recruitment. ABC may or may not be set at equilibrium yield (EY), which is the harvest that would maintain a stock at its current level, apart from the effects of environmental conditions. It may be set lower than MSY in order to rebuild depleted stocks.

There is presently no procedure to estimate the ABC in the FCZ. The ABC for each fishable population is set each year by state agencies on the basis of prespawning biomass estimates or estimates based on egg deposition. Procedures for setting ABC's in each state are described in the source document. These ABC's actually represent the acceptable annual biological catch from the entire resource which spawns in U.S. waters since all mature herring move inshore to spawn each year. Accordingly, the ABC's developed by each state are considered the best available and will be used in this plan. Whenever necessary, the ABC's shall be combined to form a composite ABC for a management area. For example, the ABC for the Central Management Area will be a composite of ABC's for northern California, Oregon and southern Washington.

A special circumstance exists in the Northern Management Area. Since the major component of the herring biomass in the FCZ spawns in Canadian inshore waters, the ABC of these stocks must be incorporated into the composite ABC. Canadian authorities will be asked to provide annual estimates of ABC. If no estimates are available, the Plan Development Team will estimate the ABC from the best available data, including published and unpublished reports, historical and present catches, age composition estimates and knowledge of abundance and recent trends in abundance.

7.4 Optimum Yield (OY)

Optimum yield (OY) may be obtained by a plus or minus deviation from ABC for purposes of promoting economic, social, or ecological objectives as established by law and public participation processes. Ecological objectives, where they primarily relate to biological purposes and factors, are included in the determination of ABC. Where objectives relate to resolving conflicts and accommodating competing uses and values, they are included as appropriate with economic and/or social objectives. OY may be set higher than ABC in order to produce higher yields from other more desirable species in a multi-species fishery. It might be set lower than ABC in order to provide larger-sized individuals or a higher average catch per unit of effort.

The issues discussed in Chapter 9 (e.g., herring as forage, natural fluctuations) suggest that a cautious management approach is warranted. Therefore, the total harvest (inshore and offshore) should not exceed the ABC for each Management Area, and thus the maximum OY will not exceed ABC.

The OY for each area will be selected by the Council and will conform with objectives of the plan which favor existing fisheries while increasing the diversity of fishing opportunities.

The intent of this plan is to clearly establish a cooperative management arrangement between state agencies and the Council. Under this arrangement, the Council would set the offshore OY component (OY_O) and the states would set the inshore OY component (OY_I).

The Council must first set OY_O. It is expected that this will be a fixed quota which will not vary between years or which will be set by predetermined formula. Any changes in OY_O will require a plan amendment.

Each year the states will determine the ABC's. Inshore quotas (OY_I) will then, by definition equal the ABC less the offshore OY or $OY_I = ABC - OY_O$.

8.0 TOTAL ALLOWABLE LEVEL OF FOREIGN FISHING (TALFF)

The TALFF for Pacific herring under this plan is set at zero. The following considerations clearly demonstrate that there is currently no harvestable surplus of herring and that there will be no surplus in the foreseeable future.

1) At the present time, herring which spawn in U.S. waters are fully utilized. Stocks of herring which occur in exploitable abundance in the FCZ migrate inshore to spawn and reside in inshore waters from six to nine months each year. Harvest of these herring has traditionally occurred during the inshore phase of their annual migration pattern.

2) That fraction of the transboundary stock which spawns in Canadian waters is fully exploited by Canadian fishermen.

3) The U.S. harvesting capacity and market exceed MSY, ABC, and OY for stocks that spawn in the U.S.

4) Herring are a significant source of food for many commercial and recreational fish species. They are also consumed by several species of marine mammals and birds. Any temporary or short-term surplus should accrue to the "forage stock".

5) This plan is intended to diversify and stabilize the markets for herring. It is likely that a decrease in present major markets (e.g., sac-roe) will result in an increased effort of fishermen and processors to produce other herring products (e.g., food or bait).

9.0 MANAGEMENT ISSUES

The purpose of this chapter is to consolidate and summarize the most significant management issues which are discussed in various sections throughout the plan. These issues must be considered during formulation of a management plan for herring, establishment of the acceptable biological catch, and setting of optimum yield levels.

9.1 Mixed Stock Versus Single Stock Management

The best available information suggests that herring from many different spawning areas intermingle freely during the offshore feeding phase of their life history, and thus form mixed stock aggregations. A fishery on a mixture of stocks of differing status significantly complicates effective management. It is virtually impossible in a mixed stock fishery to devise measures which will protect the small or depleted stocks while allowing intensive harvests on large stocks or those which may appropriately be harvested at a higher level.

If an offshore fishery for herring develops in the FCZ, it will in all likelihood fish on mixed stocks. Scientists from Europe, Canada and Alaska attending the 1980 Alaska Herring Symposium concluded "that in a mixed stock fishery, the percentage removal is related to the percentage of mixing of the stocks, and that if management objectives are for a general level of exploitation, then underfishing of the smaller stocks is as likely as overfishing" (Melteff and Wespestad, 1980). Thus, a mixed stock fishery in the FCZ, harvesting healthy stocks at the same rate, cannot be precluded. However, weak stocks which need protection may require reduction or elimination of an offshore fishery.

Herring stocks in most areas covered by the plan are in satisfactory condition. However, the Strait of Georgia (Northern Puget Sound) herring stocks declined in 1980 and 1981 resulting in a complete closure of the sac-roe fishery in 1981. If this stock continues to decline, or does not recover, it will require special consideration during the development of a management regime for coastal waters.

9.2 Herring as a Forage Species

Perhaps the most controversial and emotional issue to be addressed in developing a commercial herring fishery is the role of herring as food for fish, birds, and marine mammals. One viewpoint insists that herring should not be harvested by man, but should be left for exclusive use as food for other animals. This viewpoint holds that any utilization of herring by a commercial fishery will directly impact and reduce the abundance and health of other animal populations. The opposing viewpoint holds that herring is only one of many food organisms in the marine environment and that most predators are opportunistic and will prey on whatever food organism is available. The latter viewpoint contends also that a reasonable level of fishing will have no observable impact on herring recruitment since poorly understood environmental interactions cause wide fluctuations in herring recruitment in the absence of commercial herring fisheries. Refer to section 6.3 for further discussion of the role of herring in the ecosystem.

Currently, many management agencies explicitly or implicitly recognize the importance of herring as a forage item and set conservative exploitation rates. This management concept will be considered when developing the final management regime.

9.3 Regional Management Needs

Three management areas have been considered in recognition of special management requirements. Biological, social, and political considerations vary by area. Since these areas and stocks have unique characteristics, each will be considered separately when developing management measures.

In the northern area, large stocks of herring which spawn in Canada intermingle with stocks of Puget Sound origin. These stocks apparently move freely across the international boundary (see section 9.4). Further, it has been demonstrated, through the experimental fishery, that these stocks can be harvested by trawls on the high seas. Special consideration must be given to existing inshore fisheries as well as to the international implications of an offshore fishery when considering appropriate management measures for this area.

Virtually all of the stocks in the large central area are small and spawn in the embayments and river estuaries along the coastline of southern Washington, Oregon, and northern California. The discrete nature of these small stocks in this large area suggests special consideration is necessary. It is probable that in this extended area less mixing of stocks occurs and an offshore fishery could target on discrete stocks.

Large populations of herring are found in the southern area. These fish spawn primarily in San Francisco Bay and, to a lesser degree, in Tomales and Bodega Bays. At the present time, these herring are fully harvested by an inshore fishery for sac-roe. Virtually nothing is known of the offshore distribution and migration pattern of herring in this area. Development of an offshore fishery will have a direct impact on the inshore roe fishery since offshore fishing would be on the same stocks which subsequently spawn inshore.

9.4 International Implications of Transboundary Stocks

As discussed previously, the large transboundary aggregations of herring which feed in offshore waters during the summer, subsequently move inshore to spawn in Canada and the United States. The best information available indicates that at least 80 percent of the total herring aggregation in the transboundary area is comprised of fish which ultimately spawn in Canadian inshore waters. It follows then that if a commercial fishery developed in this area of the FCZ, a large percentage of herring taken would be of Canadian origin. There are at least two important management implications which arise from the transboundary nature of these stocks.

1. Any U.S. fishery which develops in offshore waters will harvest a high proportion of fish which spawn in Canadian waters. Consequently, the impact of an offshore fishery on U.S. stocks is minimized since, hypothetically, only one out of five fish harvested is destined for U.S. Puget Sound waters. Thus, while such a fishery will increase the value of herring harvested by U.S. fishermen, it will decrease the overall value of herring, because of the larger loss to Canada.

2. There is an obvious international management issue involved in any offshore fishery for herring. This issue is beyond the purview of the plan and must be addressed by the U.S. and Canadian governments.

The management regime developed in this plan will consider the biological and management issues evolving from an offshore fishery as they relate to the impact on inshore U.S. stocks.

9.5 Marketing Issues

In recent years, the vast majority of herring harvested in Washington, Oregon, and California have been sold for sac-roe. Prices for roe herring increased dramatically until late 1979, when they plummeted (see section 5.0). Market conditions for roe herring since that time have been very unstable. During the 1980/81 new year season, Japanese consumers resisted the high-priced herring roe and ex-vessel prices in California subsequently declined from $1,200 to $600-800 per ton from December 1980 to January 1981. There are indications that salted fish and roe are becoming less popular in Japan due to consumers' interest in reducing salt in their diet (Pacific Fishing, February 1981). It is possible that high prices, combined with health concerns, may significantly and permanently decrease demand for herring roe.

In contrast to the concerns over the roe market, interest in fisheries for food and bait have been increasing. These contrasting market conditions were considered when developing management options. It may be beneficial to long-term market stability to broaden the base of utilization from what is now essentially a single-use fishery to a multi-use fishery. High quality herring can be harvested in the FCZ in the summer and early fall. However, adult prespawning herring, which are found in inshore waters, are of low fat content and are less acceptable to the sophisticated food markets of Europe. In order to diversify and broaden the market base, it is likely that an offshore fishery would be necessary.

9.6 Natural Fluctuations of Herring

Herring typically exhibit wide natural fluctuations in abundance. If a large-scale fishery is imposed on a stock or stocks of herring which are at the low point of a natural fluctuation, severe recruitment and abundance problems can result. Consequently, any management regime for herring should consider this aspect of the natural history and establish conservative optimum yield levels to prevent depletion of a resource during years of naturally low abundance.

10.0 MANAGEMENT MEASURES

10.1 General Management Strategy

Results of the herring management strategy model discussed in section 7.0 and Appendix II provide useful insights into impacts of various management strategies and harvest levels. Strategies or harvest rates which drive the population to low levels or extinction are rejected without further discussion.

The concept of a constant annual inshore quota is also rejected because large natural fluctuations would make it necessary to set the quota low enough to prevent overharvest during years of low abundance. The constant quota would thus result in underharvest in all years of average or above average abundance.

Proportional harvest with a minimum biomass necessary before any harvest is permitted and harvest of fish surplus to spawning requirements are viable management strategies. Both protect against overharvest and permit large average catches and prevent long-term depletion of the resource.

10.1.1 Surplus stock concept

The strategy which allows harvest of all fish surplus to spawning requirements produces a high average yield with a large standard deviation, and would result in very large quotas in some years and no quota in many others.

The range in quotas is due to large natural fluctuations in abundance and a prohibition of all fishing at population levels below the prescribed spawning requirement. This concept assumes an "optimum" spawning stock size which will produce optimum recruitment. Since there is no documented relationship between spawning stock and the resulting recruitment except at extremely small stock size, the highly variable quotas appear to be an unnecessary and an undesirable product of this strategy. Further, this management concept reduces the total stock size to the same level each year, and in essence establishes a recruitment fishery.

10.1.2 Proportional harvest concept

Proportional harvest with a minimum biomass before any harvest is permitted, maintains long-term stock stability with much more stable harvest levels. This method is advantageous because of the need to protect stocks which have been reduced to low levels and the uncertainty of a spawner-recruit relationship. At high levels of abundance, this procedure produces catches lower than the "surplus stock" method but provides carry-over of adults into subsequent years, thus spreading harvest of a single year class over several years. This carry-over buffers the impact of years of subaverage recruitment. In conformance with management regimes of the three states, this strategy of harvesting 20 percent of the biomass will be the basic management strategy (see section 7.0). This concept conforms with and enhances achievement of objectives of the plan.

10.1.3 Considerations of an offshore fishery

The proportional harvest strategy is applicable to inshore herring harvest in all areas and is currently the management policy of the state fisheries agencies of Washington, Oregon, and California. If offshore fisheries are to occur, however, the proportional harvest strategy must be modified to accommodate them. Since objectives of the plan favor existing circumstances and because little is known about the ocean segment of herring life history, any initial offshore fishery must be small, but also must be of sufficient magnitude to be economically viable. A small, constant annual quota would allow an offshore fishery. Results of the management model suggest that an offshore quota in addition to an inshore proportional harvest is an acceptable option. Options which include an offshore harvest component are presented below.

10.2 Management Measures for the Fishery as a Whole

The following proposed measures may apply to all management areas or may be selected for each area.

10.2.1 Fishing gear

Seines and pelagic trawls are effective, historically-used commercial gears for herring. Although gill nets are also effective for catching herring, the potential incidental catch of salmon and the prohibition of set nets (a form of gill nets) for other species in the FCZ precludes consideration of this gear for herring (Pacific Fishery Management Council, 1981). No other fishing gear has been proven effective for high seas herring fishing and, thus, only seines and pelagic trawl options are proposed for this fishery.

Option 1 - Pelagic trawls only

Pelagic trawls must conform with the following requirements:

(a) codends must be single walled;

(b) bottom line at trawl mouth must be without protection (rollers, bobbins, or discs) and may not exceed 1.75 inches in diameter, which includes twine necessary for seizing material;

(c) sweeplines, including bottom leg of bridle, must be bare;

(d) no minimum mesh size requirements.

Rationale:
Pelagic trawls are a proven effective fishing gear for herring on a worldwide basis. The limited recent commercial domestic and foreign herring catches in the Pacific Council's FCZ have been taken by pelagic trawls. The trawl description above was modified from that used in the Groundfish FMP and is intended to prevent intentional contact with the bottom to minimize incidental catches of non-pelagic species. Small mesh sizes are necessary to harvest herring. Imposition of any mesh size regulations on the herring fishery designed to protect juveniles of other species would preclude a herring fishery. Further, observers of the experimental offshore herring fishery report a very low incidence of juvenile fish. Accordingly, no mesh size regulations are proposed.

Incidental catch proposals are presented in section 10.2.2.

Option 2 - Pelagic trawls and seines

Seines are an extremely effective gear for herring, and are currently used in the inshore sac-roe fisheries in all Pacific areas. It is entirely possible that seines could be effective for herring fishing in the FCZ. Seines are currently banned from the FCZ in waters adjacent to Washington and Oregon for all species to prevent directed or unavoidable catches of salmon. The use of seines for herring is an acceptable option from a biological perspective if catches are carefully monitored. No minimum mesh restrictions are proposed (see the mesh size discussion under pelagic trawls).

10.2.2 Incidental catch allowances

Incidental catches of other species are governed by other plans.

It is proposed that incidental catches of groundfish[1/] be 15 percent of the catch per trip or 3,000 pounds per trip, whichever is greater.

It is proposed that there be no retention of salmon, crabs, shrimp or other species of finfish or shellfish.

Rationale:
Large catches of groundfish were made during the early stages of the experimental offshore herring fishery. Catches of groundfish decreased as the fishermen gained experience in offshore herring trawling. The proposed incidental limits for groundfish will allow for unavoidable catches, and discourage targeting on groundfish with small mesh nets.

10.3 Area Specific Measures

1/ See appendix III for a complete list of groundfish.

10.3.1 Management Areas

Management areas have been described in section 1.4 and Figure 1.1. The special characteristics of each area are discussed in section 9.3. Briefly, the three management areas are:

Southern Area - U.S.-Mexico border to Cape Mendocino, California (40°30' N. latitude),

Central Area - Cape Mendocino, California (40°30' N. latitude) to Cape Elizabeth, Washington (47°20' N. latitude),

Northern Area - Cape Elizabeth, Washington (47°20' N. Latitude) to the U.S.-Canada boundary.

10.3.2 Southern management area (U.S.-Mexico border to Cape Mendocino)

10.3.2.1 Quotas

Option 1 - Status quo

Herring fisheries will be managed by the State of California. There will be no herring fishing in the FCZ.

Rationale:

Herring stocks are fully exploited in this area. Catches made in the FCZ would cause a commensurate reduction of quotas for inshore fisheries.

Option 2 - Status quo in state waters and a 1,000 - 4,000 mt fixed annual quota in the FCZ

Rationale:

This option would provide flexibility in management in the event of low harvest inshore not due to conservation issues (i.e., market collapse, strikes). A small fishery offshore would also diversify markets and may improve long-term market stability for the overall herring fishery. A harvest in the FCZ would require inshore quota reduction of about 80 percent of the offshore catch. For example, an offshore harvest of 1,000 mt would necessitate about an 800 mt quota reduction inshore to account for the offshore harvest, less what could be accounted for by natural mortality and other life processes. A quota lower than 1,000 mt would probably be insufficient to provide an economically viable fishery.

Option 3 - Status quo in state waters and a variable annual quota in the FCZ of 1,000 to 4,000 mt.

Rationale:
This option is intended to provide a minimum 1,000 mt quota in the FCZ with the ability to increase the quota to a maximum of 4,000 mt without plan amendment. The Regional Director is authorized to increase the quota after consultation with, and approval by, the Council.

The Council will consider the following factors prior to approving an increase.

1) The condition of the herring stocks contributing to the offshore biomass.

2) Current and past inshore harvests.

3) Market conditions for herring harvested inshore and offshore.

4) Other appropriate factors.

Any increase above the minimum 1,000 mt quota must be allotted at least 30 days prior to the start of the fishing season.

10.3.2.2 Seasons

Option 1 - The FCZ will be open all year (Inshore seasons are set by state fishery agencies)

Rationale:
This option provides minimal regulation. Fishermen would be able to fish at any time subject to quota limitations. Since adults move inshore to spawn

during the November-March period, it is likely that an offshore fishery during these months would catch primarily juvenile and sexually immature herring. It is also possible that discrete stocks of late spawning herring would be accesable to harvest in the winter months.

<u>Option 2 - The FCZ will be closed to all herring fishing from November 1 through March 30</u>

Rationale:
This option would protect small and immature herring and those discrete stocks of late spawning adults which may be available. It would also reduce potential enforcement problems in the inshore fishery resulting from misreporting of inshore catches to avoid inshore regulations.

<u>10.3.2.3 Fishing gear</u>

If coastwide uniformity is considered to be unnecessary, an option presented in section 10.2.1 can be selected for this area.

<u>10.3.2.4 Incidental catch allowances</u>

Uniform catch allowances for all areas are proposed in section 10.2.2.

<u>10.3.3 Central management area</u> (Cape Mendocino, California, to Cape Elizabeth, Washington).

<u>10.3.3.1 Quotas</u>

<u>Option 1 - Status quo</u>

At the present time, all herring fisheries are in state waters. The fisheries will be managed by the states. There will be no herring fishing in the FCZ.

Rationale:
Many small discrete spawning stocks are present in this large area, each of which is managed independently. No large stocks or aggregations of herring

have been observed in either coastal waters or the FCZ. Virtually nothing is known about the ocean distribution of herring in this area, nor of the degree of intermingling of spawning stocks.

Since herring stocks in this area are apparently fully utilized, any offshore catches would directly impact inshore quotas, the inshore management regime, and could result in overharvest of individual spawning stocks.

Option 2 - Status quo inshore and a 100-500 mt quota for an offshore experimental fishery. No more than 50-250 mt can be harvested in waters adjacent to a single state.

Rationale:
An offshore experimental fishery with observer coverage could provide valuable information on the distribution and relative abundance of offshore herring aggregations. A small quota, combined with the provision to distribute catches along the entire area (conversely, to prevent the entire quota being taken from a small area) may minimize the impacts on onshore fisheries or on discrete spawning stocks. However, the distribution requirement may be hard to enforce.

10.3.3.2 Seasons

Option 1 - The FCZ will be open all year

Rationale:
This option provides minimal regulation. Fishermen would be able to fish at any time subject to limitations of the experimental fishing permit. Since adults move inshore to spawn during the January-April period, it is likely that an offshore fishery during these months would catch primarily juvenile and sexually immature herring. Discrete stocks may be vulnerable as they move inshore to spawn.

Option 2 - The FCZ will be closed to all herring fishing from January 1 through April 30

Rationale:
This option would protect small and immature herring and discrete stocks of late spawning adults. It would also reduce potential enforcement problems in the inshore fishery resulting from misreporting of inshore catches to avoid inshore regulations.

10.3.3.3 Fishing gear

If coastwide uniformity is considered to be unnecessary, an option presented in section 10.2.1 can be selected for this area.

10.3.3.4 Incidental catch allowances

Uniform catch allowances for all areas are proposed in section 10.2.2.

10.3.4 Northern Management Area (Cape Elizabeth to the U.S.-Canada border)

10.3.4.1 Quotas

Option 1 - Status quo

Rationale:
At the present time, northern Washington spawning stocks are fully exploited in state waters. There will be no herring fishing in the FCZ. Fisheries in state waters will be managed by Washington State.

Option 2 - Status quo inshore and a small offshore quota (1,000-4,000 mt)

Rationale:
This option would provide flexibility in management in the event of a low harvest inshore, which was not a result of conservation issues (i.e., market collapse, strikes). A small offshore fishery would also diversify markets and may improve long-term market stability for the overall herring fishery.

A harvest in the FCZ could result in a smaller inshore catch. For example, if 1,000 tons were harvested in the FCZ, the estimated reduction to Washington stocks would equal 160 mt (see Table 5.3).

Assuming ex-vessel values of $475 per ton, a 1,000 ton fishery would generate $.475 million in income to fishermen. About half of the 160 mt inshore reduction (80 mt) would be to the northern Puget Sound sac-roe fishery. At a 20% harvest rate of observed inshore biomass, this would result in a 16 mt reduced harvest and a 64 mt reduced spawning escapement. At a constant combined harvest rate for inshore and offshore fishing, the full 80-ton reduction would come at the expense of the inshore harvest. The other 80 tons of inshore biomass loss would be proportionally distributed among other Puget Sound stocks. At an average value of $1,000 mt, $16,000 would be lost to the sac-roe fishery in the first case, and $80,000 would be lost in the second case. For a more complete treatment of economic trade-offs. see section 5.4.

Option 3 - Status quo quo in state waters and a variable annual quota in the FCZ OF 1,000 to 4,000 mt.

Rationale:
This option is intended to provide a minimum 1,000 mt quota in the FCZ with the ability to increase the quota to a maximum of 4,000 mt without plan amendment. The Regional Director is authorized to increase the quota after consultation with, and approval by, the Council.

The Council will consider the following factors prior to approving an increase.

1) The condition of the herring stocks contributing to the offshore biomass.

2) Current and past inshore harvests.

3) Market conditions for herring harvested inshore and offshore.

4) Other appropriate factors.

Any increase above the minimum 1,000 mt quota must be allotted at least 30 days prior to the start of the fishing season.

10.3.4.2 Seasons

Option 1 - The FCZ will be open all year (Inshore seasons are set by state fishery agencies)

Rationale:
This option provides minimal regulation. Fishermen would be able to fish at any time subject to quota limitations. Since adults move inshore to spawn during the December-May period, it is likely that an offshore fishery during these months would catch primarily juvenile and sexually immature herring and discrete stocks of herring as they moved inshore to spawn.

Option 2 - The FCZ will be closed to all herring fishing from December 1 through May 31

Rationale:
This option would provide a measure of protection to small and immature fish and discrete stocks of herring moving to spawning areas. It would also reduce potential enforcement problems in the inshore fishery resulting from misreporting of inshore catches to avoid inshore regulations.

10.3.4.3 Fishing gear

If coastwide uniformity is considered to be unnecessary, an option presented in section 10.2.1 can be selected for this area.

10.3.4.4 Incidental catch allowances

Uniform catch allowances for all areas are proposed in section 10.2.2.

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APPENDIX I

1. Coordinates of the U.S.-Canada Boundary in the ocean waters west of the U.S. and Canada.

48°29'37.19"	N. lat.,	124°43'33.19"	W. long.;
48°30'11"	N. lat.,	124°47'13"	W. long.;
48°30'22"	N. lat.,	124°50'21"	W. long.;
48°30'14"	N. lat.,	124°54'52"	W. long.;
48°29'57"	N. lat.,	124°59'14"	W. long.;
48°29'44"	N. lat.,	125°00'06"	W. long.;
48°28'09"	N. lat.,	125°05'47"	W. long.;
48°27'10"	N. lat.,	125°08'25"	W. long.;
48°26'47"	N. lat.,	125°09'12"	W. long.;
48°20'16"	N. lat.,	125°22'48"	W. long.;
48°18'22"	N. lat.,	125°29'58"	W. long.;
48°11'05"	N. lat.,	125°53'48"	W. long.;
47°49'15"	N. lat.,	126°40'57"	W. long.;
47°36'47"	N. lat.,	127°11'58"	W. long.;
47°22'00"	N. lat.,	127°41'23"	W. long.;
46°42'05"	N. lat.,	128°51'56"	W. long.;
46°31'47"	N. lat.,	129°07'39"	W. long..

2. Coordinates of the U.S.-Mexico Boundary in the ocean waters west of the U.S. and Mexico.

32°35'22.11"	N. lat.,	117°27'49.42"	W. long.;
32°37'37.00"	N. lat.,	117°49'31.00"	W. long.;
32°37'37.00"	N. lat.,	117°49'31.00"	W. long.;
31°07'58.00"	N. lat.,	118°36'18.00"	W. long.;
31°07'58.00"	N. lat.,	118° 6'18.00"	W. long.;
30°32'31.20"	N. lat.,	121°51'58.37"	W. long.

A HARVEST STRATEGY MODEL (HMODEL) FOR PACIFIC HERRING

Fishery management plans prepared for regional councils under the FCMA require consideration of maximum sustainable yield (MSY), modifications from MSY for social and economic reasons to provide Optimum Yield (OY), and a mechanism to determine how much fish may be harvested, Acceptable Biological Catch (ABC). Mathematical fishery models are often employed to calculate MSY, or to calculate fishing effort which will produce MSY. Single number solutions, however, cannot describe natural fluctuations inherent in fish populations. As a result, a computer simulation model called "HMODEL" was constructed to reflect year-to-year variations in Pacific herring biomass and to allow an assessment of the effects of harvest strategies. Before describing and discussing the results of this model, the more traditional models will be presented and their major drawbacks discussed.

TRADITIONAL MODELING

The concept of MSY has provided a convenient objective which is still commonly applied (Gulland, 1979), but has numerous deficiencies (Larkin, 1977). The mathematical models used to calculate MSY are usually logistic--surplus production types (Schaefer, 1954) using catch and effort, or the yield-per-recruit equation (Beverton and Holt, 1954) using a variety of population parameters. The models assume an equilibrium in the population associated with a degree of stability in the environment during the time period considered.

Mortality and Recruitment

Because the population models used to calculate MSY are only suitable for long-term averages, they may be marginal for MSY determination of any individual fish species which undergoes large natural fluctuations. These types of models cannot forecast discontinuous events, which is one of the primary problems facing management of herring populations. Many of the fluctuations are caused by various combinations of density-independent and density-dependent mortalities. Two competing density-dependent mortalities are compensatory, which decreases large abundance and increases low abundance to stabilize at an equilibrium point, and depensatory, which increases mortalities at low abundance and decreases mortalities at high abundance.

Competing mortality rates are most clearly reflected in the variability of recruitment experienced by many species of fish. One of the most common characteristics of herring populations is variable recruitment. In some stocks of herring, for example, the range of recruitment may vary by a factor of 100 times as noted for the Atlanto-Scandian herring by Gulland (1972). The strong year classes appear at very irregular and widely spaced intervals, but sustain the population for a number of years until the next strong recruitment occurs. Gulland estimated that 50 percent of the herring harvest from the Atlanto-Scandian stock for a 50-year period (roughly 1920-1970) came from three or four exceptional year classes. This herring stock may be an extreme example.

There is a tendency among clupeoids for longer-lived fish to experience greatest variability in recruitment and, therefore, biomass, while shorter-lived fish show more constancy (Murphy, 1977). Murphy suggests that clupeoid stocks with short life spans cannot withstand very large fluctuations in recruitment because inevitable recruitment failures will occur in consecutive years to reduce the population to a level where depensatory mortality will prevent stock recovery. Fishing necessarily reduces the stock size and the average age of a fish population. Thus, fishing increases relative fluctuation for a stock. Murphy noted that successive low recruitments occur in unfished populations without massive declines; stock collapse has been observed only for heavily fished populations.

For certain species of fish, the abundance of adults (spawners) in a given year has some predictive relationship to the later recruitment of young fish. Therefore, fishery management objectives can include optimum spawning escapement levels which, in turn, should generate the maximum amount of young fish. Salmon are an example of a species regulated for optimum escapement levels for individual runs.

One reason for the lack of a clear spawner-recruit relationship for herring is that large, environmentally-caused fluctuations of abundance occur. Observations on both Atlantic (Clupea harengus harengus) and Pacific herring show that fluctuations in year class strength are normal: eggs and larvae may experience very high natural mortality due to variable environmental conditions at each life stage. At normal levels of adult populations, environmentally-caused mortality of the young stages is far more important in determining the ultimate number of young fish than the actual abundance of spawners. Very heavy fishing pressure, however, may reduce the adult population so low that too few eggs or larvae will be produced to maintain the population (Pope, in press; Ulltang, in press).

Eggs and larvae produced from a depleted population will be susceptible to many of the same mortalities as experienced by the fish when they were more abundant. Poor environmental conditions could have a devasting effect on a depleted population, and very low recruitment would result. Good environmental conditions would increase recruitment, but recruitment would be limited by the very small amount of eggs produced. At low abundance levels, depensatory mortalities may operate. Ulltang (in press) theorizes that under certain conditions, herring populations which have been reduced to very low levels may not be able to recover to normal levels, even in the absence of fishing.

Herring characteristically lay adhesive eggs in shallow water on marine vegetation (Pacific herring) or on the bottom in waters up to several hundred meters deep (Atlantic herring). In both subspecies of herring, increased numbers of egg layers on spawning substrate tend to increase the mortality of eggs (compensatory mortality). Observations by European (Rannak, 1971, Burd and Wallace, 1971), Soviet (Galkina, 1971), Canadian (Taylor, 1971), and U.S. (Penttila and Day, 1975) scientists confirm that hatching success of individual eggs decreases dramatically as egg deposition thickness increases beyond several layers. Mortality of thick egg layers also increases through predation by birds (Cleaver and Franett, 1945) and fish, and from washup on the beaches in rough weather (Hourston and Rosenthal, 1977). If high numbers of larvae result from a particular spawning, predation will increase and the larvae will experience density-dependent mortality (Cushing and Harris, 1973). Large herring populations, which spawn at densities of multiple egg layers, will experience heavy loss of both eggs and larvae as a direct result of the large populations size. Because of high mortality of eggs and larvae, most herring populations can be characterized as possessing a spawning surplus, that is, adult fish whose loss will not affect the reproductive potential of the population.

An average spawner-recruit relationship for herring can be approximated: above a threshold value of spawning escapement, recruitment varies independently of escapement, so that an average recruitment level may be calculated. Below the threshold value, recruitment decreases to zero as escapement decreases to zero. The predictive value of this relationship is poor, however, because of the extreme environmentally-caused fluctuations in recruitment for any value of spawning biomass and because of the difficulty in determining the threshold value.

Examples

Gulland (1970) and Francis (1974) consider models (yield per recruit and logistic) under which preliminary estimates of maximum sustainable yield can be obtained by setting instantaneous fishing mortality (F_{opt}) equal to instantaneous natural mortaility (M). Age composition analysis for some herring populations indicate that M = 0.4. Over a year (assuming F = M), total deaths equal $1-e^{-(F+M)} = 1- e^{-.8} = 0.55$. One half of the deaths attributable to fishing implies a fishing rate of 0.55/2 = .28. Reduction of the fishing deaths from 28 percent to a lower harvest level can be justified on the following points:

1. The conclusion that $F_{opt} = M$ applies only under certain conditions not fully met by herring. Herring are known to be susceptible to heavy fishing and recruitment declines at low population levels. Therefore, following Francis (1974), $F_{opt} < M$.

2. Management of herring should recognize that herring are an important forage organism, and require lower fishing mortality than might otherwise be possible.

3. Assessment of stock condition indicates that series of weak year classes frequently enter the fishery, and fishing intensity must be conservative.

These are points which should be considered before using this simplified model to set actual harvest rates.

A simple Beverton and Holt yield per recruit model using isometric growth (Gulland, 1969) was used to examine aspects of fishing pressure and age at entry. The following parameters were used as generally representative of a wide range of herring stocks:

$$W_{\infty} = 230 \text{ gr.}$$
$$K = 0.5$$
$$t_{0} = -0.15 \text{ yrs.}$$

The yield-per-recruit isopleth diagram (Figure 1) shows yield in grams per fish alive at one year. The figure shows that yield per recruit increases continuously as fishing mortality increases and that herring should be fished at a young age. At fishing mortalities less than about 0.2, the yield-per-recruit model suggests fishing on herring as young as possible. At higher fishing mortality, the age at first fishing for maximum yield per recruit increases to a maximum of approximately 2 1/2 years. The age of maturity for most Pacific herring is about three years of age.

The management strategy of fishing very hard, especially on prereproductive fish, to harvest maximum yield per recruit does not take into account potential effects of fishing on recruitment. Reduction of stock biomass and elimination of older age groups from the population caused by heavy fishing may cause recruitment failure if spawning escapement falls below the escapement threshold level. Yield-per-recruit does not take into account potential effects of fishing on recruitment. Reduction of stock biomass and elimination of older age groups from the population caused by heavy fishing may cause recruitment failure if spawning escapement falls below the escapement threshold level. Yield-per-recruit considerations alone suggest a fishing strategy that is clearly dangerous to the herring populations.

MODEL

No fishery for herring exists in offshore waters of the PFMC region. Research efforts have been limited to a joint U.S.-Canada research cruise in 1979, which provided quantitative abundance estimates in the U.S.-Canada transboundary area, an experimental fishery off the Washington coast on 1979 and 1980, and several Canadian research cruises. Data for the offshore phase of herring life history is very limited. A substantial amount of information has been gatered and analyzed for inshore herring. This information must be applied by inference to offshore areas. This model is a way to consolidate the data and inferences so that a range of management options may be explored. The model specifically separates inshore and offshore harvest as a result of the PFMC objectives to define the effects of an offshore fishery on the inside fisheries.

Two basic philosophies have been developed within Washington, California, and British Columbia to tailor existing fishery harvest rates to observed population size and spawning requirements. The first of these harvest strategies sets an optimum spawning escapement level and permits all additional fish to be considered harvestable surplus. The second strategy requires a harvest proportional to the population size.

Strategy I is currently applied only in British Columbia. A desired spawning escapement is calculated as the amount of fish required to deposit eggs in the intensity expected to produce maximum larval production (Hourston, personal communication); all additional fish are considered harvestable surplus. This permits very strong pulse fishing during years of heavy recruitment. However, by cropping off all available surplus, there are no fish allowed to carry over for subsequent years to balance or compensate for a series of poor year classes. Biomass declines during periods of poor recruitment are enhanced.

Stragegy 2 is based on the philosophy that a harvest schedule should parallel the natural cycles and abundance observed in nature. This allows a portion of strong abundance to remain unharvested so that the population will have a sufficient carry-over to buffer the effect of several years of poor recruitment. As a safeguard, a proportional harvest strategy may include a minimum population biomass below which no harvest is allowed. This minimum abundance should be above the spawning escapement threshold at which reductions in escapement cause reductions in recruitment. This will protect against continued harvest into low population levels where recruitment can be affected by the spawning population size. One drawback to the proportional harvest strategy is that during periods of higher than normal abundance, intensities of spawning may be high to the point that egg mortality will increase. In periods of heavy intensity spawning, increased catches may be made without jeopardizing reproductive potential of the population.

A third possible strategy, which is not currently used for management, is a constant quota, independent of biomass. We can examine the effects of any of these strategies applied to inshore or offshore herring fisheries.

Basic Model Concept

The model is based on a traditional fisheries yield-per-recruit model (Ricker, 1975; Beverton and Holt 1957). Each year is divided into time periods to which factors of recruitment, growth, and mortality are applied. Individual fish get larger as age increases (growth), numbers of individuals within a group diminish through time from natural and fishing deaths (mortality), and young fish periodically enter the population (recruitment). Growth, mortality, and recruitment are not constant through a year, so the year must be divided into intervals within which the rates are assumed constant. Standard fishery equations (growth and mortality are applied exponentially; see Ricker, 1975) allow biomass and harvest calculations for each interval. For a given set of biological parameters, one may compare biomass, harvest levels and population stability for a series of management strategies to determine effect on yield.

Limitations to the Model

Simulation models for fish such as herring must be used with caution. As discussed earlier, one of the dominant characteristics of herring population biology is variable recruitment and wide natural fluctuations in population size. Recruitment cannot be predicted in advance, so recruitment in the model is based on a stock recruitment curve plus lognormal error to generate variability. Long-term simulations provide averages that may be representative, but actual management must recognize and protect aginst the possibility of recruitment problems. Recruitment from year to year may be serially correlated, but our model does not incorporate serial correlation, and may not adequately represent the possibility of a series of poor recruitments (i.e., the possibility of depensatory mechanisms affecting mortality). Second to recruitment fluctuations, the most serious limitation is the inability to address the problem of discrete herring stocks mixing in off-shore waters. At best, our model simulation can be conducted for each identified population; however, separate runs for individual populations will not be able to consider interactions between stocks. Stock separation, including information on population parameters and abundance, is very poorly understood. Parameters in the model (e.g., mortality and growth) are the best available, but any errors will be reflected in the model output. These population parameters do not vary greatly between populations and are less than other variables.

Although the model cannot be used to accurately predict the course of events in a given year, it does give our best estimate of the long-term consequences of different harvest management strategies.

Detailed Construction of the Model

Figure 2 shows the time period (I-IV), the monthly instantaneous rates (M, F_o, F_s, G), fishing quota (Q_o, Q_s.), and recruitment (R), which are needed to go through the model's calculations.

While the time intervals can be changed, those used are generally represenative of herring in the U.S.-Canada transboundary region. The calculations for each time period proceeds as follows:

Period I

The year starts April 1 with an estimate of spawning escapement (B_S) following the inside sac-roe fishery. For a period following spawning, biomass will decrease due to natural mortality (M), although the decrease will partially be offset by growth (G).

Hence, three months after spawning, $B_O = B_S \exp(-3(M-G))$.

Period II

Additional mortality (F_O) is added if an offshore fishery occurs. The model assumes a late summer-autumn season for offshore fishing.

Hence, after three months of fishing; $B_F = B_O \exp(-3(M+F_O-G))$.

Period III

This period begins with the recruitment of young fish into the fishery. Although young fish and adults coexist in many areas, they tend to be segregated by size into separate schools. The model calculates that recruitment (R) to the adult (spawning) population occurs only after an offshore fishery, on the assumption that the new recruits are smaller than required for human consumption use, and that the schools of small fish would sustain only a minimal harvest.

Hence, $B_I = (B_F+R) \exp(-5(M-G))$.

Period IV

This period of one month contains the inshore sac-roe fisheries. Assuming the monthly instantaneous mortality rate is F_S, $B_S = B_I \exp(-(M+F_S-G))$, and the model returns to Period I.

Stochastic Considerations

In order to simulate variability which occurs in a natural system, stochastic variation is included in three areas of the model. In all cases, variability is included as a lognormal error. This is, variability is "added" to the variable X, by forming

$$y = X\varepsilon \qquad \log(\varepsilon) \sim N(0, \sigma^2).$$

For moderately small values of σ, the bias in y will be small and σ will be the coefficient of variation of y.

Variable recruitment is therefore generated as follows. Because recruitment is primarily of three year olds, the spawning biomass surviving the sac-roe fishery (B_s) from three years previous is applied to the spawner-recruit curve (Figure 2), to get the recruitment value R'. Stochastic recruitment is generated as ($R = R'\varepsilon$), where ε is a lognormal deviate described previously.

Because catch quotas are based on estimated, and not actual population parameters, lognormal errors are placed on these parameters also. The ocean quota is determined by knowing the quantity B_0; but B_0 must be inferred from an estimate of B_s; and B_s is, in turn, not actually known, but estimated. In our model, an estimate of B_0, say $\hat{B}_0$, for the purpose of generating quotas, is determined by first "estimating" B_s with $B_s = \hat{B}_s\,\varepsilon$, where ε is a lognormal deviate, and then applying three months of growth and natural mortality: $\hat{B}_0 = \hat{B}_s \exp(-3(M-G))$. Similarly, the quota for the inside sac-roe fisheries is determined from an "estimate" of B_I: $\hat{B}_I = B_I\,\varepsilon$.

It is important to realize that the model always "knows" the "true" population sizes B_0 and B_I, but the quota formulas must be based on $\hat{B}_0$ and $\hat{B}_I$.

Once the quotas are determined, however, the catches are taken from the true population sizes. These gyrations are only to simulate the effects due to quotas being based on estimates of population size, and not true population levels.

Quota Determination

Because the prinicipal goal of this model is to investigate the implications of various harvest strategies, the model contains a very general formulation for determining a quota from an estimate of population biomass. Generally, for both the offshore and inshore fisheries:

$$Q = 0 \text{ if } \hat{B} < \tau$$
$$Q = \gamma \text{ if } \tau \leq \hat{B} < \alpha$$
$$Q = \gamma + \beta\ (\hat{B} - \alpha\ ) \text{ if } \alpha \leq \hat{B}$$

where Q = annual catch

γ = a constant catch level

β = a constant harvest proportion

B = biomass at the start of fishing

α = a threshold (or reserve) population

τ = a switch that sets $Q = 0$ if $B < \tau$, but allows calculations to proceed if $B \geq \tau$

The parameters α, β, γ, τ are set by the manager.

Given $\hat{B}$, and α, β, γ, τ, an allowable Q is thus clearly determined. However, for our model, Q must be converted to an equivalent monthly instantaneous fishing mortality rate (i.e., the exact instantaneous rate which will result in a harvest of Q under the exponential model). This instantaneous fishing rate is determined by solving

$$Q = \frac{BF}{F+(M-G)}(1-e^{-(F+M-G)T})$$

where B is the actual population size prior to the fishery, and T is the duration of the fishery in months. This equation is easily solved using iteration.

By setting combinations of α, β, γ, and τ equal to zero, various harvest strategies can be simulated. The three basic strategies are:

1. α stragey (proportion of total biomass which exceeds a thresnold),
   $\gamma = \tau = 0,\ 0 < \beta \leq 1,\ \alpha > 0 \rightarrow Q = \beta\ (\hat{B}-\alpha)$.

2. β strategy (proportion of total biomass),
   $\gamma = \alpha = \tau = 0,\ 0 < \beta \leq 1 \rightarrow Q = \beta\ \hat{B}$

3. γ strategy (constant quota), $\beta = \tau = 0,\ \gamma > 0 \rightarrow Q = \gamma$

Any of the three basic strategies may incorporate the switch .

For example, the Washington State strategy (β strategy with switch τ) of harvesting sac-roe herring at 20 percent of the population if the population exceeds 9,000 tons, but prohibiting harvest for lower abundance is simulated by setting

$$\gamma_o = \beta_o = \gamma_s = \alpha_s = 0,\ \beta_s = 0.2,\ \tau_s = 9{,}000.$$
$$\rightarrow Q_s = 0.2\ \hat{B}_I \text{ if } \hat{B}_I \geq 9{,}000$$
$$Q_s = 0 \qquad \text{if } \hat{B}_I < 9{,}000$$

A strategy such as used for northern anchovy harvest (α strategy) which allows a catch of one-third of all anchovy in excess of 10^6 tons follows by setting

$$\gamma_o = \tau_o = \beta_s = \tau_s = 0,\ \beta_o = .333,\ \alpha_o = 10^6$$
$$\rightarrow Q_o = 0.333\ (B_o - 10^6).$$

Canadian strategy (α strategy) of harvesting all herring in excess of a spawning escapement goal derives from $\gamma_o = \beta_o = \gamma_s = \tau_s = 0,\ \beta_s = 1.0,$

α_s = spawning goal $\quad Q_s = B_I - \alpha_s$ if $B_I \geq \alpha_s$

$Q_s = 0$ if $B_I < \alpha_s$

Results

For results to be useful, there must be confidence that the model responds in a way that is expected from theory. The simplest comparison to consider is the long-term average population biomass expected when no fishing occurs. Theoretically, $\bar{B} = \bar{R}/Z$ (Ricker, 1975), where $\bar{B}$ is average biomass, $\bar{R}$ is

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average recruitment, and Z is total mortality. For $\bar{R}$ = 100,000 tons, Z = M-G = 0.3, $B = \frac{100,000}{0.3}$ = 333,333 tons. The model calculated an average spawning escapement (B_s) of 337,645 tons for a 100-year simulation. Similar agreements occur for other combinations of $\bar{R}$ and Z. The model simulates average long-term conditions in a manner expected from theory.

The model offers a wide variety of management strategies, but to introduce the types of results possible, initial discussion will concentrate on inshore harvest only. Unless otherwise specified, results are based on the parameters M = 0.4, G = 0.1, Rmax = 100,000 tons, with simulations of 100 years. The coefficients of variation of the three stochastically-influenced variables (R, $\hat{B}_o$, $\hat{B}_I$) are all 0.2.

The model was run for a constant harvest proportion (β strategy, $Q = \beta_s B_I$) ranging from β_s = 0.2 to β_s = 0.6. At β_s = 0.2, the population and harvest were stable for the entire 100 years (Figure 3). Spawning escapement averaged 172,830 tons with a standard deviation of 20,273. Harvest averaged 44,959 tons with a standard deviation of 9,636 tons. An increase of β_s to 0.4 caused a long-term decrease to near zero levels (Figure 4). However, the decline did not occur for over 25 years, indicating that heavy fishing pressure may be maintained if recruitment cycles are favorable, but when an unfavorable recruitment cycle occurs, heavy fishing will drive the population to critically low levels. At β = 0.6, the population trend is inexorably down, to near extinction in just over 10 years (Figure 5).

As a protective mechanism, one may use the τ parameter to prevent harvest at low biomass levels. At β_s = 0.4 but τ_s = 100,000 tons (i.e., R = τ = 100,000 tons), the population is protected against continuous decline (Figure 6). For the first 25 years with β_s = 0.4, the biomass values track in parallel fashion for τ = 0 and τ = 100,000. However, once the critical recruitment problem occurs, the population rebounds off the reserve (τ), but crashes without the reserve. During the 100-year simulation (Figure 6), predicted harvest averages 54,264 tons with standard deviation of 21,624 tons. This harvest is higher than using β = 0.2 (Figure 2), but is also plagued by many years of zero harvest.

A contrasting strategy harvesting all fish above a spawning reserve (α strategy, $Q = \hat{B}_S - \alpha_S$) also shows long-term stability (Figure 7) but with larger year-to-year variation than observed for the β strategy (Figure 2). For $\alpha_S = 150{,}000$ tons, catches average 49,043 tons, but with a standard deviation of 41,316 tons. Many years have no harvest or very low harvest, but other years will have extremely large catches.

The conclusion from this set of runs is that a threshold, either a spawning reserve (α) or switch (τ) will protect against too high harvest. But neither of these strategies will be able to prevent large fluctuations in abundance or harvest. The least variation came from a constant proportion of harvest (β strategy). The switch τ is a good companion to the β strategy in case higher than desired harvest inadvertently occurs.

Addition of an offshore harvest can be tested for effects on the inshore fishery. For illustrative purposes, the simplest example is the α strategy and a constant offshore quota (γ_0). Adding $\gamma_0 = 3{,}000$ tons to the inshore strategy of $\alpha_S = 150{,}000$ and $\beta_S = 1.0$, increases the average offshore harvest by 3,000 tons (0 to 3,000), while the average inshore harvest decreases by 2,330 tons (51,608 to 49,278) for a net gain of 670 tons:

Offshore catch =	3,000	(3,000 ton increase)
inshore catch =	49,278	(2,330 ton decrease)
total	52,278	(670 ton increase)

Spawning escapement remains essentially unchanged by the offshore fishery, and the increased catch is possible because of harvesting fish destined to die through natural causes prior to spawning.

For $\gamma_0 = 3{,}000$ tons, and $\beta_S = 0.2$, the average harvest offshore increases from 0 to 3,000 tons, while inshore harvest decreases by 1,229 tons (from 44,959 to 43,720), for a gain of 1,771 tons:

offshore catch =	3,000	(3,000 ton increase)
inshore catch =	43,720	(1,229 ton decrease)
Total	46,720	(1,771 ton increase)

The increased harvest comes at the expense of spawning escapement because total fishing mortality (F) increases.

For the same strategies with a 10,000 ton constant offshore harvest:

$\gamma = 10{,}000 \quad \alpha_2 = 150{,}000 \quad \beta_2 = 1.0$

offshore catch	= 10,000	(10,000 ton increase)
inshore catch	= 43,855	(7,753 ton decrease)
Total	53.855	(2,247 ton increase)

$\gamma = 10{,}000 \quad \beta_2 = 0.2$

offshore catch	= 10,000	(10,000 ton increase)
inshore catch	= 40,864	(4,096 ton decrease)
Total	50,864	(5,905 ton increase)

A similar set of runs was completed for a simulated population with the approximate characteristics of the Strait of Georgia sac-roe herring: Rmax = 5,000; M = 0.4; and G = 0.1. This is a useful run because the results can be compared to actual observations in the Strait of Georgia for the past eight years. Strategies of: $\beta_s = 0.2$; $\beta_s = 0.2$, $\tau_s = 9{,}000$; and $\alpha_s = 7{,}200$ are shown in Figures 8, 9, and 10, respectively.

The three strategies have similar average harvests, but the β strategies give much less fluctuation than does the α strategy. Also, the spawning escapement is considerably higher for the β strategy. For comparison to recent years in the Washington sac-roe fishery, estimated spawning escapement has ranged from 8,000-12,000 tons; catch has ranged from 1,600 to 4,400 tons, and estimated prefishing abundance has ranged from 9,000 to 15,000 tons.

CONCLUSIONS

The following conclusions can be made from the preceding examples of harvest strategies:

1. Of the fish harvested offshore from July through August, 77.5 percent would have returned to spawn if no fishing had occurred (22.5 percent would have died anyway). More would have returned if the offshore fishery were later in the season.

2. If the inshore harvest follows a α strategy, the offshore catch will slightly increase the total harvest without decreasing spawning escapement, through a reduction in the inshore quota. The increase would be smaller as the offshore fishery is later in the season.

3. If the inshore harvest follows a β strategy, the offshore catch will increase the total harvest; however, both inshore harvest and spawning escapement will be lower, and total fishing mortality (F) will increase. Maintaining constant F and constant spawning escapement requires a reduced β_s value, which will reduce the inshore quota further.

4. Because recruitment cannot be predicted prior to offshore harvest, any adjustment in harvest will have to be made in the inshore fishery (through α or τ) to meet spawning requirements.

5. Reduction of B_I to below α or τ, caused by an offshore fishery, will prevent an inshore harvest.

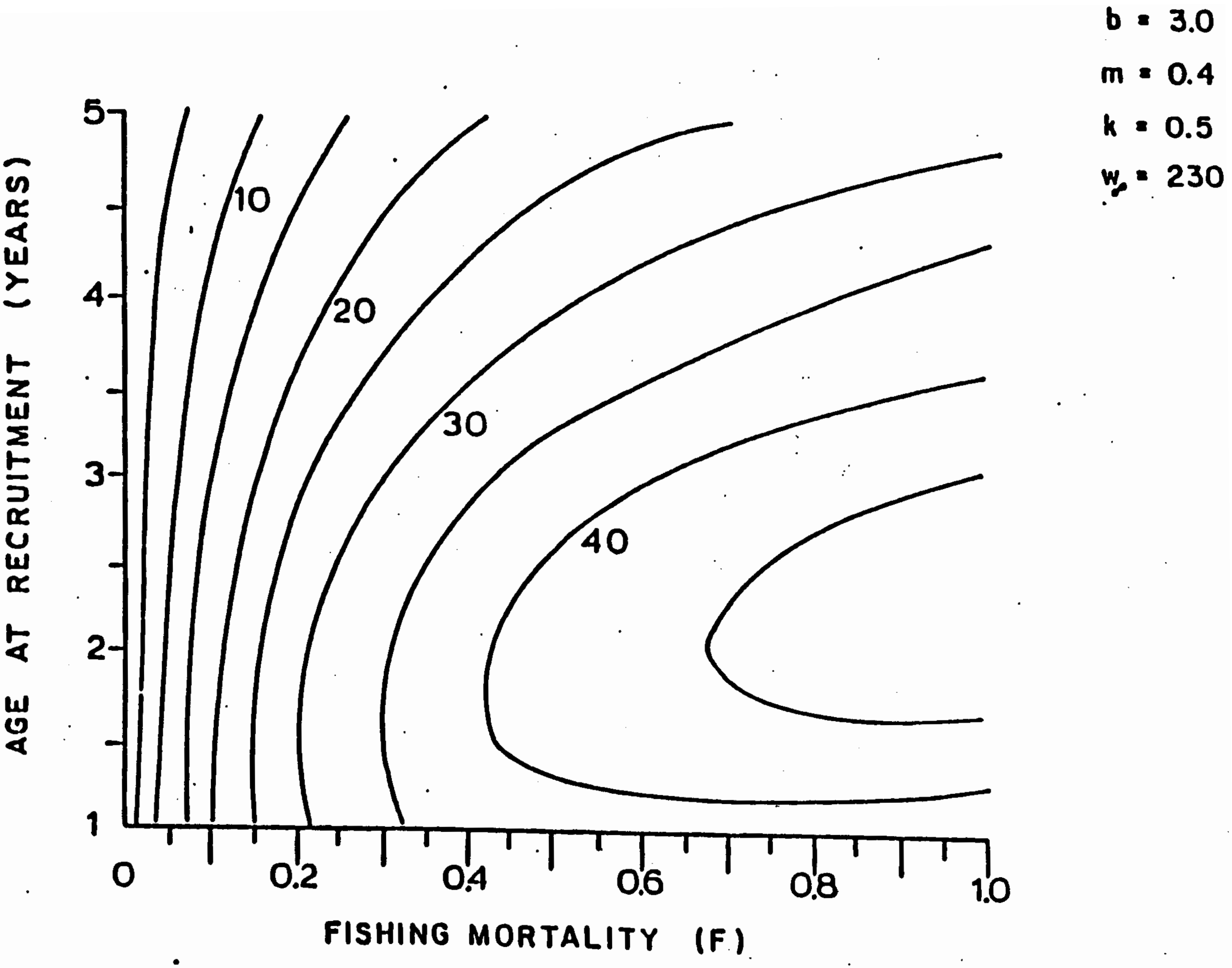

Figure 1. Yield per recruit isopleths for Pacific herring

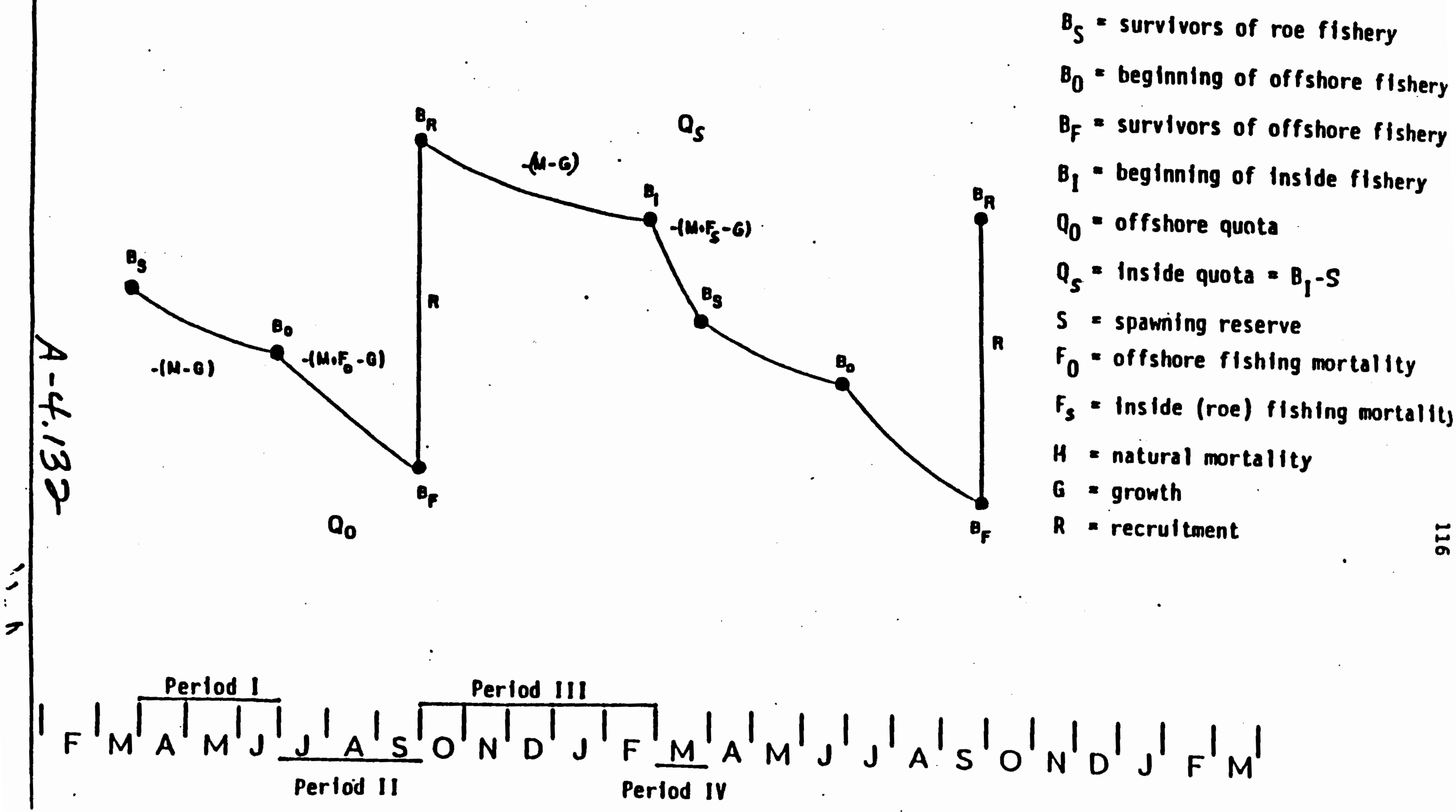

Figure 2. Basic time periods, rates, and biomass levels for herring harvest simulation.

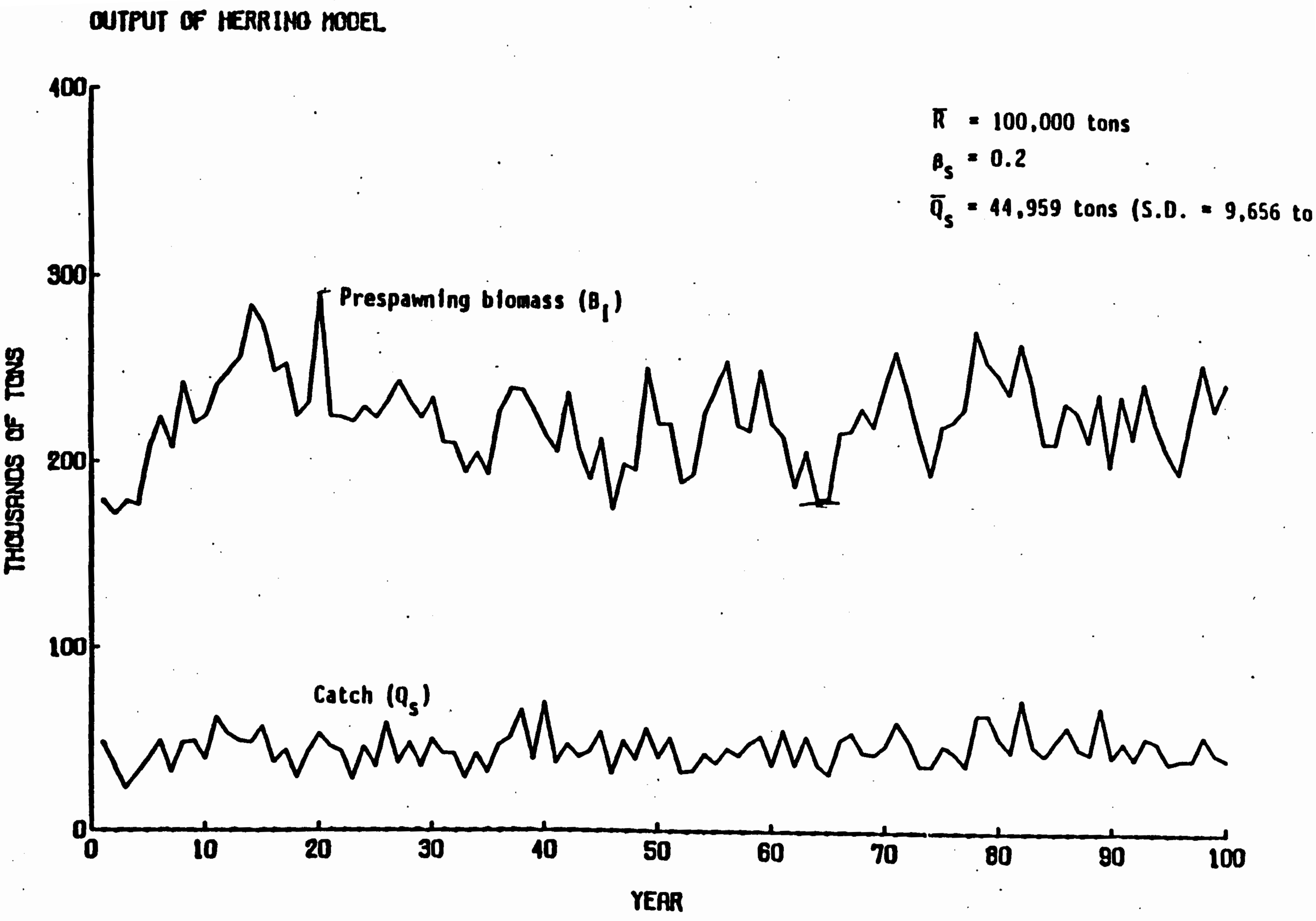

Figure 3. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 20% of prespawning biomass.

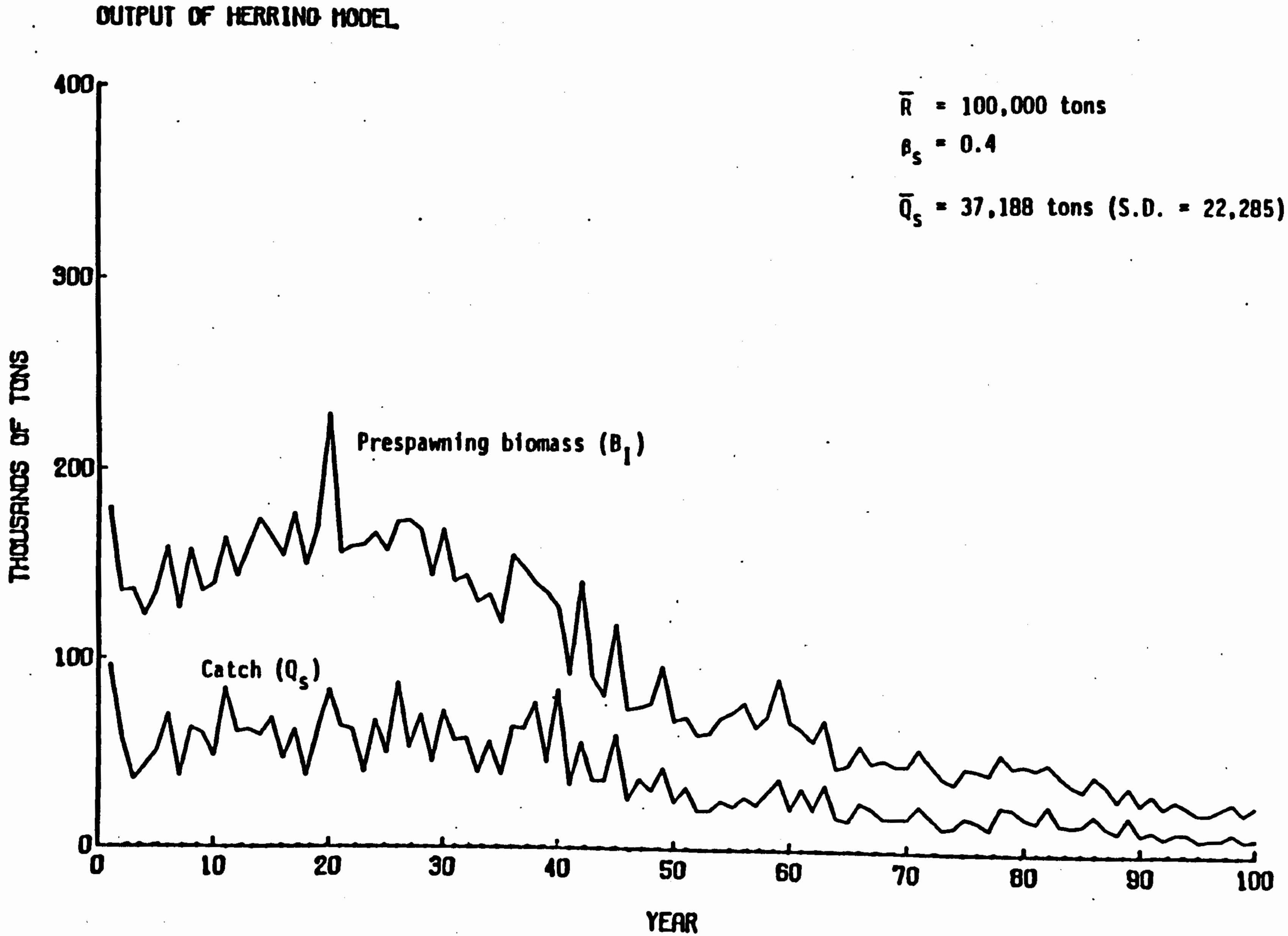

Figure 4. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 40% of prespawning biomass.

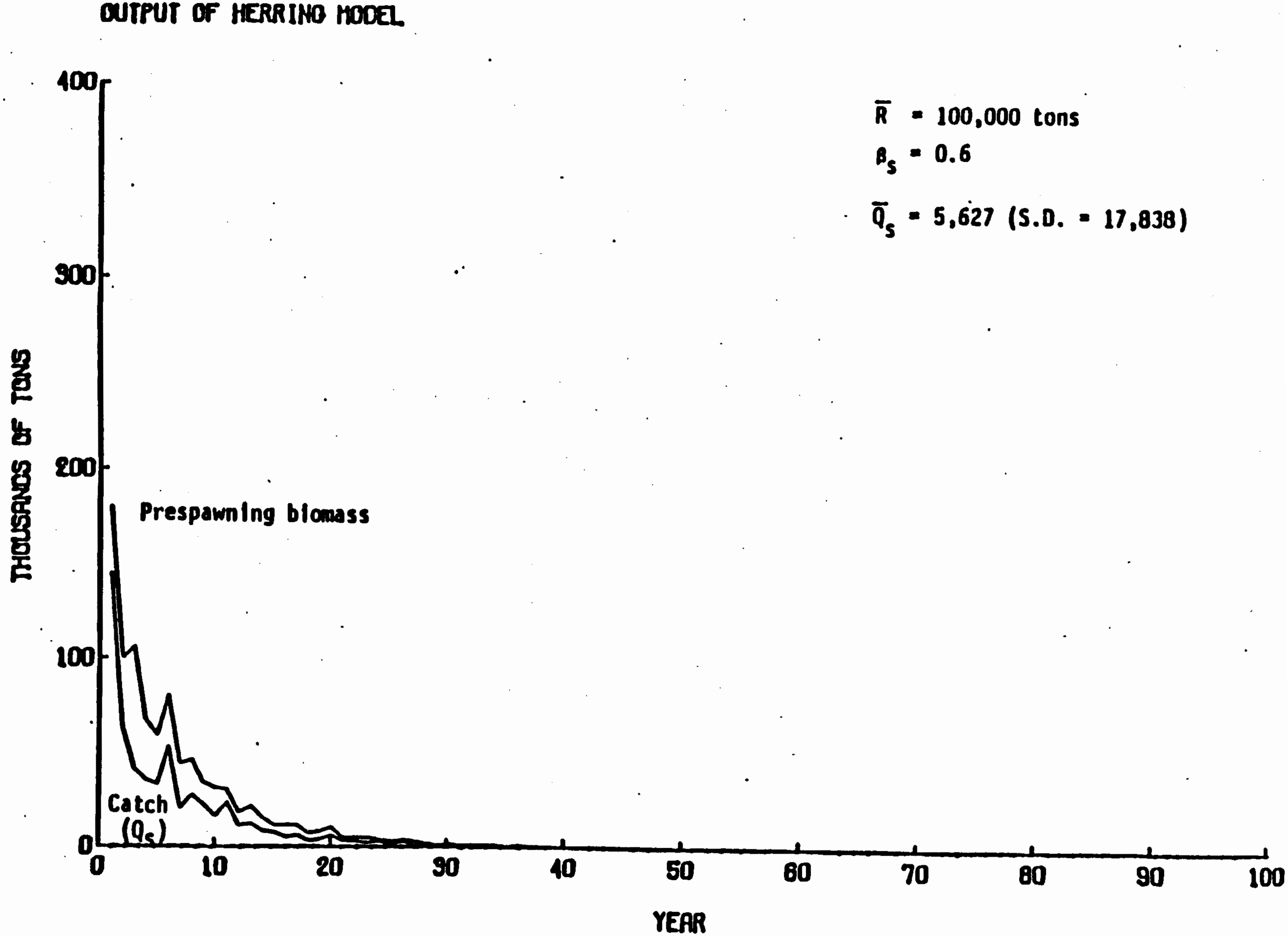

Figure 5. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 60% of prespawning biomass.

OUTPUT OF HERRING MODEL

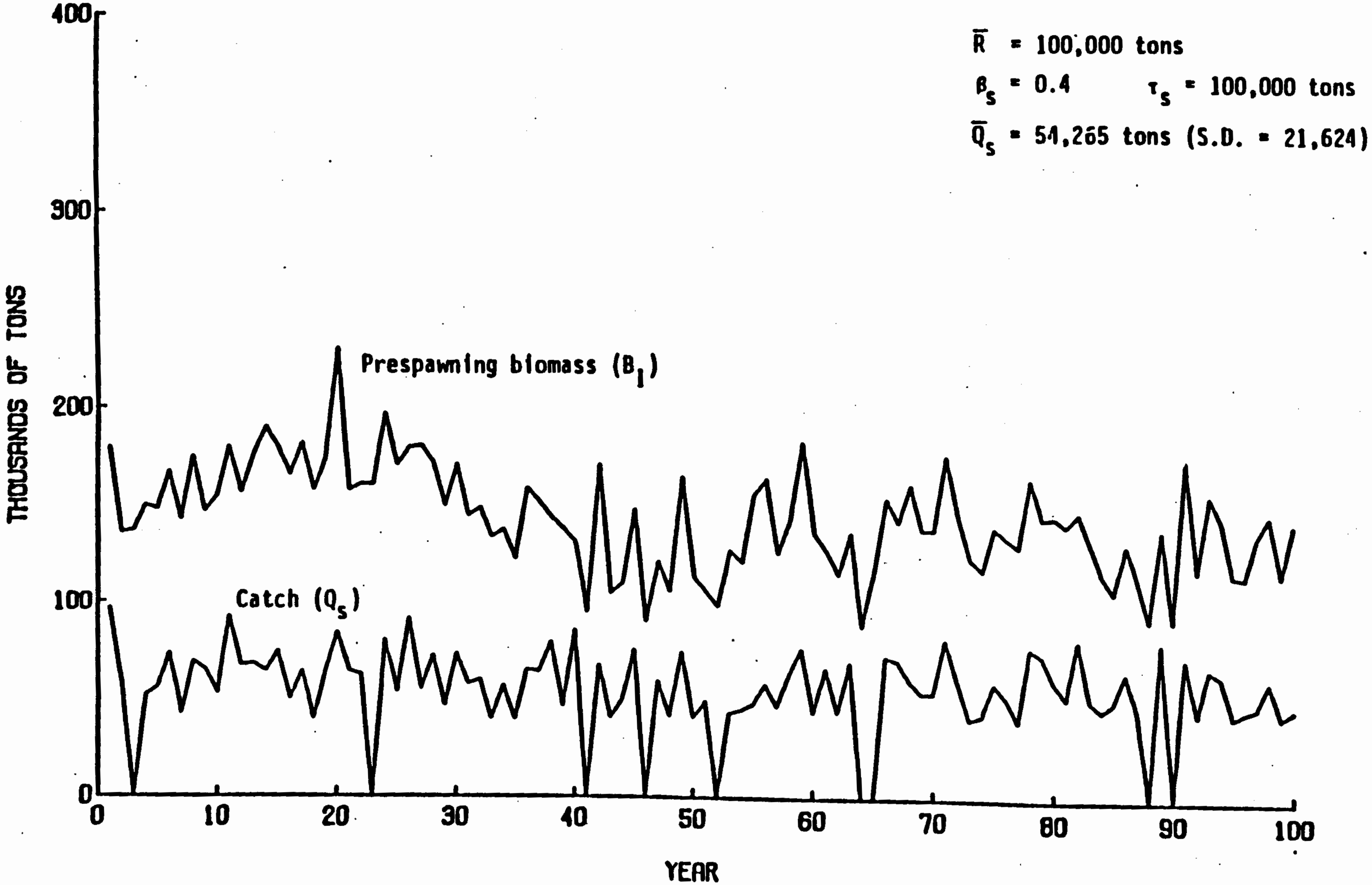

Figure 6. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 40% of prespawning biomass if the biomass exceeds 100,000 tons and 0 if [illegible]

OUTPUT OF HERRING MODEL

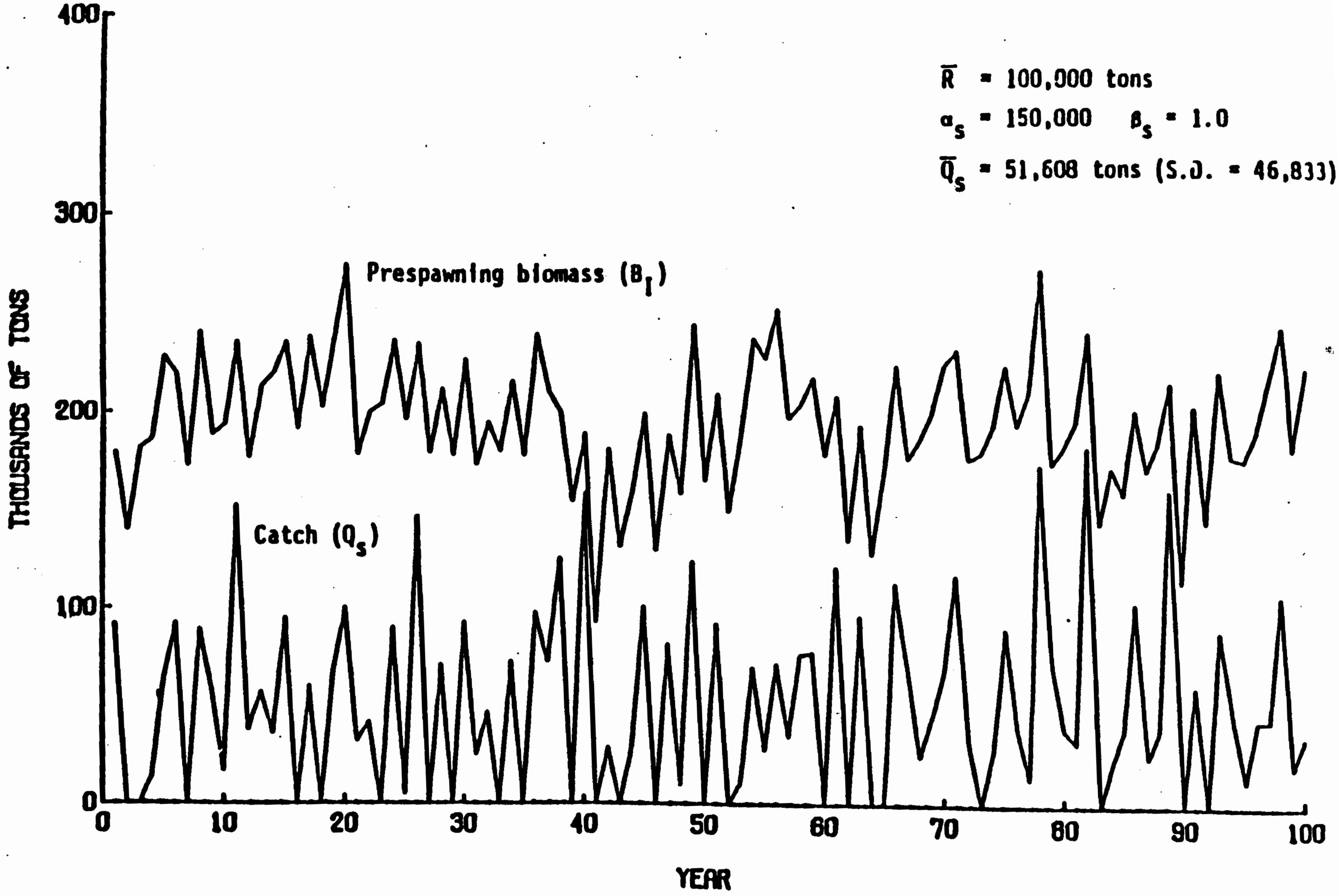

Figure 7. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is all biomass that exceeds a 150,000 ton spawning reserve.

OUTPUT OF HERRING MODEL

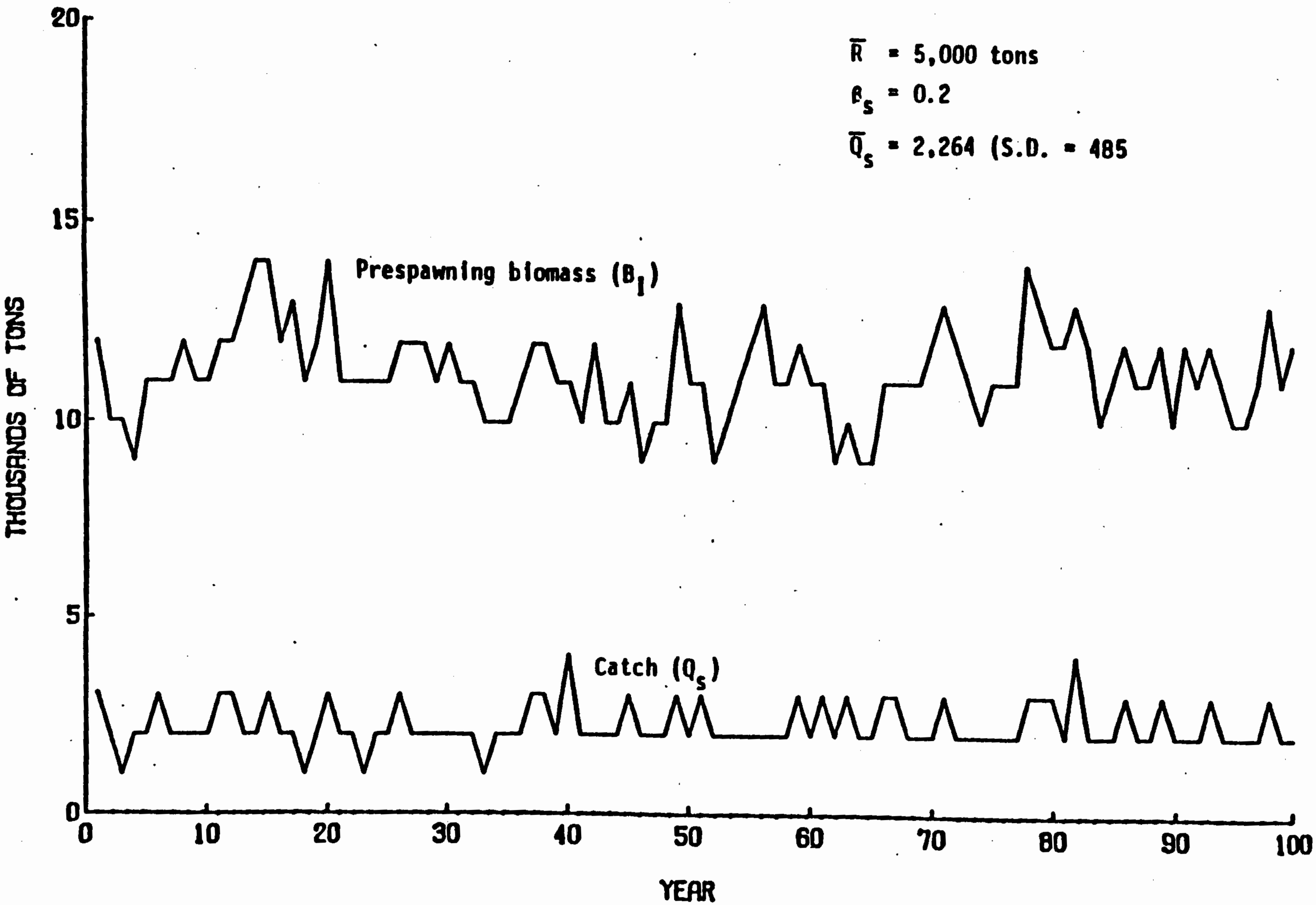

Figure 8. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 20% of prespawning biomass.

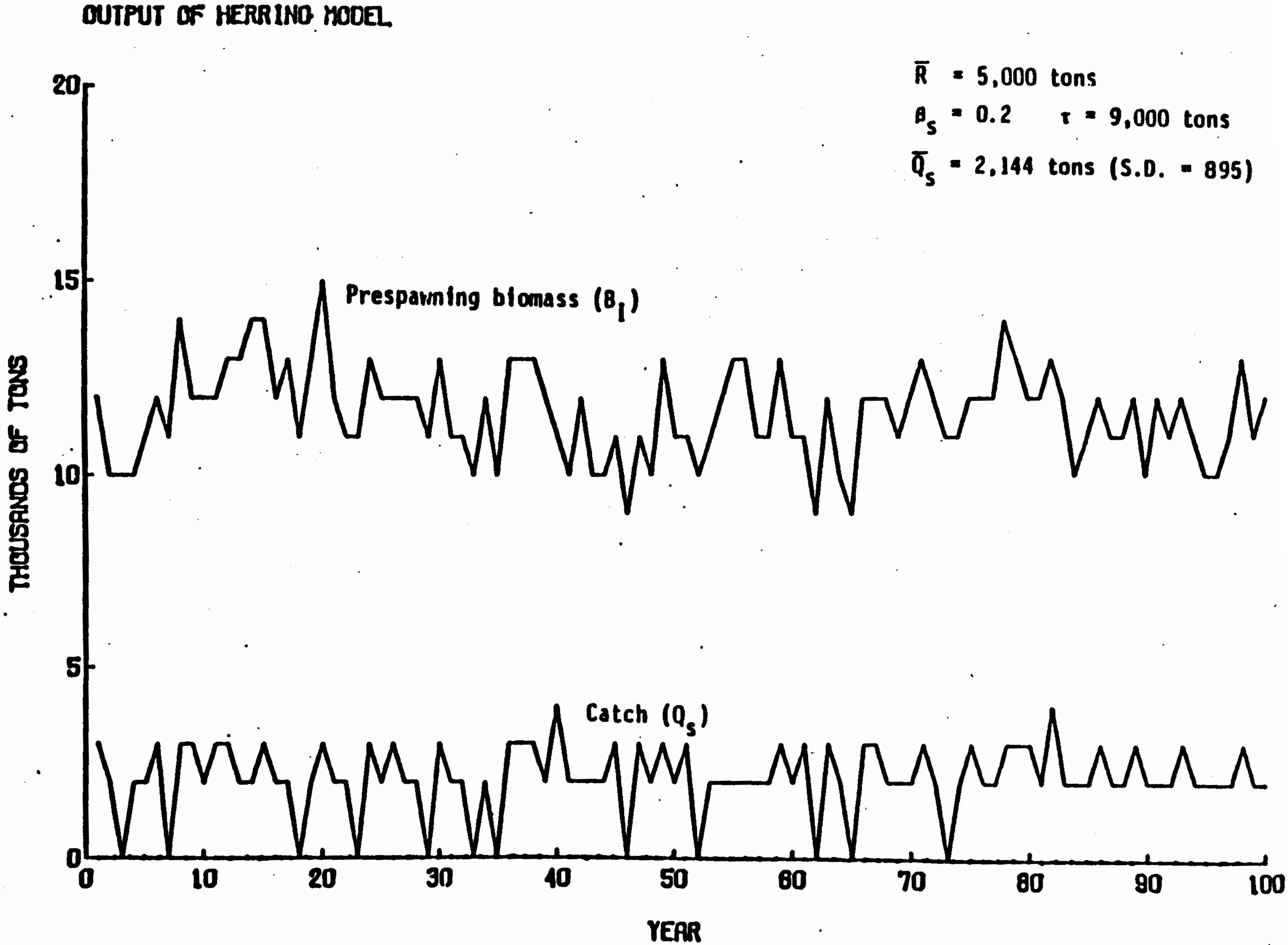

Figure 9. Yearly catch and abundance of herring simulated by HMODEL; harvest rate is 20% of prespawning if the biomass exceeds 9,000 tons, and 0 if biomass is less than 9,000 tons.

OUTPUT OF HERRING MODEL

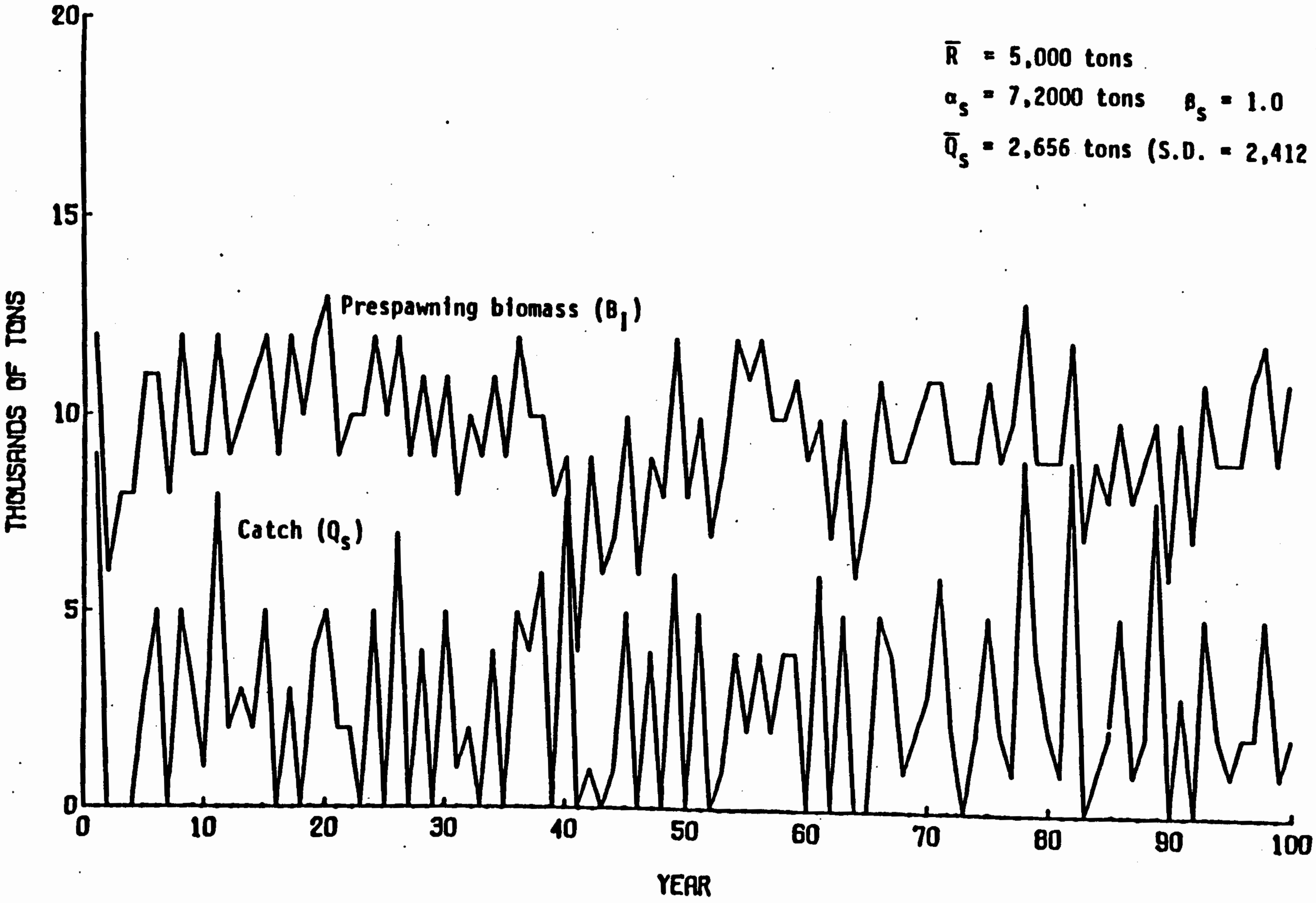

Figure 10. Yearly catch and abundance of herring simulated by IMODEL; harvest rate is all biomass that exceeds a 7,200 ton

APPENDIX III

Common and scientific names of groundfish included in the incidental catch restrictions.

SHARKS	
Leopard shark	*Triakis semifasciata*
Soupfin shark	*Galeorhinus zyopterus*
Spiny dogfish	*Squalus acanthias*
SKATES	
Big Skate	*Raja binoculata*
California skate	*R. inornata*
Longnose skate	*R. rhina*
RATFISH	
Ratfish	*Hydrolagus colliei*
MORIDS	
Finescale codling	*Antimora microlepis*
GRENADIERS	
Pacific rattail	*Coryphaenoides acrolepis*
ROUNDFISH	
Lingcod	*Ophiodon elongatus*
Pacific Cod	*Gadus macrocephalus*
Pacific whiting (hake)	*Merluccius products*
Sablefish	*Anoplopoma fimbria*
ROCKFISH	
Pacific ocean perch (POP)	*Sebastes alutus*
Shortbelly rockfish	*S. jordani*
Widow rockfish	*S. entomelas*
OTHER ROCKFISH1/	
Black rockfish	*Sebastes melanops*
Blue rockfish	*S. mystinus*
Bocaccio	*S. paucispinis*
Canary rockfish	*S. pinniger*
Chilipepper	*S. goodei*

1/ By definition, the category "other rockfish" includes all rockfish except Pacific ocean perch, shortbelly and widow rockfish.

Copper rockfish	*S. caurinus*
Cowcod	*S. levis*
Darkblotched rockfish	*S. crameri*
Greenspotted rockfish	*S. chlorostictus*
Longspine thornyhead	*Sebastolobus altivelis*
Olive rockfish	*Sebastes serranoides*
Redstripe rockfish	*S. proriger*
Rougheye rockfish	*S. aleutianus*
Sharpchin rockfish	*S. zacentrus*
Shortspine thornyhead	*Sebastolobus alascanus*
Silvergray rockfish	*Sebastes brevispinis*
Splitnose rockfish	*S. diploproa*
Stripetail rockfish	*S. saxicola*
Vermilion rockfish	*S. miniatus*
Yellowmouth rockfish	*S. reedi*
Yellowtail rockfish	*S. flavidus*
Yelloweye rockfish	*S. ruberrimus*

FLATFISH

Arrowtooth flounder (turbot)	*Atheresthes stomias*
Butter sole	*Isopsetta isolepis*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Flathead sole	*Hippoglossoides elassodon*
Pacific sanddab	*Citharichthys sordidus*
Petrale sole	*Eopsetta jordani*
Rex sole	*Glyptocephalus zachirus*
Sand sole	*Psettichthys melanostictus*
Starry flounder	*Platichthys stellatus*

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